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THE CONSEQUENCES OF NUCLEAR WAR

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BEFORE THE

SUBCOMMITTEE ON INTERNATIONAL TRADE,
FINANCE, AND SECURITY ECONOMICS

OF THE

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THE CONSEQUENCES OF NUCLEAR WAR

WEDNESDAY, JULY 11, 1984

Congress of the United States, Subcommittee on International Trade, Finance, and Security Economics of the Joint Economic Committee,
Washington, DC.

The subcommittee met, pursuant to notice, at 10 a.m., in room SD-628, Dirksen Senate Office Building, Hon. William Proxmire (vice chairman of the subcommittee) presiding.

Present: Senators Proxmire and Sasser; and Representative Mitchell.

Also present: James K. Galbraith, deputy director; and Richard F. Kaufman, general counsel.

OPENING STATEMENT OF SENATOR PROXMIRE, VICE CHAIRMAN

Senator **Proxmire**. The subcommittee will come to order.

A distinguished group of scientists revealed last year that the global atmospheric and climatic changes from a nuclear war above a certain threshold could threaten the human race and other species with extinction. This would be the result of the dust and smoke from fires caused by nuclear explosion blocking the sun and producing a "nuclear winter" that might last for several months.

It is not our intention to assess the validity of these findings. A number of Government-funded studies are underway at the National Academy of Sciences and various Government agencies to examine the nuclear winter thesis. It can be observed that the list of terrible consequences from nuclear explosions has grown steadily longer as our knowledge has improved. Radioactive fallout, electromagnetic pulse, and damage to the ozone layer were unknown to earlier nuclear experts. The likelihood is that the latest findings will be refined but not refuted.

The subject we wish to explore begins with this question: If the nuclear winter thesis is correct, what are the consequences for public policy?

We do not expect to find definitive answers to that question. Other committees are better suited to conduct the extensive investigations necessary to develop that kind of information for the full range of military, foreign affairs, and civil defense issues that need to be examined.

It is not too soon to begin the process. Indeed, it is surprising and disappointing that it is taking so long for policymakers in the executive branch and Congress to turn their attention to the policy implications of the nuclear winter thesis. It seems the way they are operating is that these are people who take an hour and a half to watch "60 Minutes."

It is a sad commentary on the Federal Government's sense of priorities that there has been so little reaction up to now to the nuclear winter findings. No subject can compare in importance to the survival of our species and the world as we know it. Yet, the committees of Congress have done little, if anything, to consider the new scientific evidence and the administration has done less. The President has spoken to the country often and as we know well on many subjects, but he's said nothing about this and the catastrophic consequences of nuclear war and what, if anything, we can and should do about it.

The Joint Economic Committee prides itself on being a catalytic agent in the policy process. We hope we can be an effective catalyst on this issue and a provocative catalyst. That's the reason we are having the hearing this morning. There are facets of nuclear warfare that come squarely under our mandate to study the economy. Several years ago, I conducted a study of the Economic and Social Consequences of Nuclear Attacks on the United States. The findings of this study and many others as well as the assumptions underlying the civil defense program need to be reexamined in light of the nuclear winter thesis. We are also interested in the budgetary and economic consequences of policies concerning strategic forces, nuclear weapons, stockpiles, and arms control.

Obviously, there are issues in nuclear warfare that go beyond economics. Our intention therefore is to share with the other committees the facts and, most importantly, the questions developed in this hearing.

What we are trying to do is to stimulate greater consideration by Congress and the administration of the policy implications of the nuclear winter. Hopefully, this will be translated into action in the form of changed policies or a clear explanation to the American people why our policies should not be changed.

One of our major purposes is to obtain from the witnesses their ideas about the questions that Congress and the administration ought to be considering on the assumption that the nuclear winter findings are correct. What, if anything, should policymakers be doing? Does the nuclear winter thesis mean we should change any of our policies? What is the essential meaning of this thesis?

It has been reported, as a result of the Freedom of Information requests of the National Resources Defense Council, that the Government has so far mostly ignored the nuclear winter findings, although a few agencies have belatedly begun studies of their own. What kind of studies should the Government be doing at this time and how long should it take to do them?

We are very honored by having this particular panel of experts who are appearing this morning. I think that they are uniquely qualified to address these questions and to help us identify the central issues raised by the latest scientific findings. All are in private life and have made valuable contributions to public service.

I suppose there is nobody who has done more to call the attention of this country to a nuclear winter and the significance than Carl Sagan. I think almost everybody acknowledges that. Carl Sagan is a professor of astronomy and space sciences at Cornell

University, a Pulitzer Prize winner, a recipient of medals for exceptional scientific achievement from NASA, and a coauthor of the Nuclear Winter Study.

Russell Murray was Assistant Secretary of Defense for Program Analysis and Evaluation in the Carter administration and was Principal Deputy to the Assistant Secretary for Systems Analysis under Presidents Kennedy and Johnson. He is presently principal at the Systems Research and Applications Corp.

Adm. Noel Gayler prior to his retirement from the Navy had been Commander in Chief of the Pacific Fleet [CINCPAC], Director of the National Security Agency, and the Deputy Director of the Joint Strategic Target Planning Staff. He is presently associated with the American Commission on East-West Accord.

Paul Warnke is a partner in the law firm of Clifford and Warnke and also serves as chairman of the Committee for National Security. Mr. Warnke was Director of the Arms Control and Disarmament Agency during the Carter administration.

Gentleman, we are very pleased to have you here. Before I call on you, I'm going to call on my colleague, a distinguished member of the Joint Economic Committee, Congressman Parren Mitchell.

OPENING STATEMENT OF REPRESENTATIVE MITCHELL

Representative **Mitchell**. Thank you very much. I don't have a full opening statement. I merely wanted to express my appreciation to you, Senator, for putting on these hearings.

I must confess that I have awfully ambivalent feelings about participating in this hearing or the seriousness of my feelings are ambivalent, because I am aware of the incredible dimensions of what this world could face, what mankind could face, and I guess my ambivalent feelings run like this. There are times when I almost feel prone to question the wisdom of God. To give man the genius that he has and yet allow that genius to be perverted into something so awful and so ugly that it could possibly destroy the world as we know it, or certainly it would enormously change the ecological systems of the world as we know it, I guess I want to question the wisdom of God sometimes by allowing us to have that kind of perverted genius.

On the other hand, I recognize that these are real facts that we must deal with and there ought to be a national policy. You are right, Bill, we don't have any kind of policy which begins to even address the peripheral dimensions of this problem.

So to the witnesses, gentlemen, I do want to express my thanks and my admiration for you. I am troubled. I am deeply, deeply troubled.

Thank you, Senator.

Senator **Proxmire**. Thank you, Congressman Mitchell.

Mr. Sagan, you're first. I understand you have a slide presentation and I don't know if it will show up with all the bright lights and so forth, but you may proceed.

STATEMENT OF CARL SAGAN, PROFESSOR OF ASTRONOMY AND SPACE SCIENCES, CORNELL UNIVERSITY

Mr. **Sagan**. Thank you, Senator Proxmire and Congressman Mitchell. I hope when the slides go on the lights will go off.

I would just like to say to Congressman Mitchell that humans made the mess we're in, and there's every reason to believe that humans can get out of the mess we're in. But not if we ignore it.

What I'd like to do is to present as briskly as I can the scientific basis and underpinnings of the nuclear winter findings, indicate something of the uncertainties, give an idea of how the effects seem to depend on the variety of possible nuclear wars that you can imagine being fought, and then at the end say some words about the implications for doctrine and policy that these findings seem to imply.

The nuclear winter discovery can be traced back to as long ago as 1971 on a project that is as far removed from nuclear war as anything you could imagine; namely, an American unmanned spacecraft mission to Mars.

In 1971 two spacecraft, Mariner 8 and Mariner 9 were launched to Mars. Mariner 8 fell into the Caribbean from where it did not return even oceanographic data, and Mariner 9 then went on alone to Mars. It was successfully injected into Mars orbit on December 14, 1971, becoming the first spacecraft of the human species to orbit another planet.

Now when the cameras examined Mars on that date they discovered nothing. The planet was featureless. There was virtually nothing you could see on Mars. That was because the planet was enveloped in a great global dust storm. The spacecraft had been guaranteed by its manufacturers to survive for 3 months in Mars orbit, and in fact it took 3 months for the Mars dust to dissipate. We were on pins and needles for all that time. Fortunately, the spacecraft lasted a full year after that and the wonderful array of Martian surface features, as we now know them, were revealed to us for the first time.

Within those 3 months we had little to study except the dust storm. There was an instrument on board the spacecraft that was able to measure the temperature at various levels in the Martian atmosphere, to examine high up at the top of the dust storm and at the middle of the dust storm and at the surface. And what was found was that the upper atmosphere of Mars was much warmer than it ordinarily is and the surface of Mars was significantly colder than it ordinarily is.

The reason isn't hard to understand. The dust was absorbing sunlight so that the dust was warmed in the upper atmosphere and warmed the air there. But because the dust obscured the Sun there was less sunlight at the surface and the surface was colder.

Well, several of us were able to do a rough calculation—it wasn't very hard—to calculate how much the atmosphere ought to be warmed, how much the surface ought to be cooled, and we were able to get close to the observed values. I mention this because it was the first attempt that many of us made to try to calculate what the effects of fine particles in a planetary atmosphere would be on the surface temperature.

Afterward, when the mission was over, we sought to apply this calculational technique to problems on the Earth. Unfortunately, we did not think of nuclear war. What we thought of were volcanic explosions. Major volcanic explosions can put fine particles into the upper atmosphere and stratosphere, and it is well known that there are small global temperature coolings following major volcanic explosions. An example is the 1815 explosion of the Indonesian volcano Tambora, which resulted in the year of 1816 being known in Europe as the year without a summer. It snowed in July. That was caused by less than 1° global temperature decline. We were able to calculate for such major volcanic explosions what the global temperature decline ought to be and again came out quite close to the observed values.

I should stress that while a 1° global temperature decline doesn't sound like very much, according to the National Academy of Sciences, a 1° global temperature decline is enough almost to wipe out all wheat growing in Canada. So a 1° or 2° or 3° global temperature decline can be very significant. I stress this because in the nuclear winter findings we are talking about not a few degrees but tens of degrees.

The study that I'm going to describe was performed by four colleagues and myself. From the last names of the authors, Turco, Toon, Ackerman, Pollack, and Sagan, this study has been known as TTAPS, which considering the nature of the results is perhaps not an inappropriate acronym.

There are essentially three sets of calculations. In the first, we run a large variety of possible nuclear wars and trace the consequences. The results depend on how many nuclear weapons are used, what their yields are, what targets they're directed to—that's most important—and what altitude the nuclear weapons are exploded at. An important question is the dependence of the climatic results on the assumed nuclear war characteristics.

A second set of calculations involves a microphysical program in which we have to calculate how many fine particles of what sort are injected into what altitude in the atmosphere and how long they stay up.

The third set of calculations is called a one-dimensional radiative-convective program. It calculates how much light is deposited at various altitudes and at the surface as a function of time.

Low-yield nuclear weapons carry their fine particles into the lower atmosphere. High-yield ground bursts carry fine particles into the upper atmosphere. Weapons of yields of 100 kilotons or less deposit their fine particles almost entirely in the lower atmosphere, or troposphere, while nuclear weapons of yields of one megaton or more deposit their fine dust particles in the upper atmosphere, or stratosphere.

The reason this is important is essentially that the higher up the particles are deposited, the longer they stay in the atmosphere and, therefore, the greater the duration of the consequent climatic effects. Fine particles injected into the lower troposphere survive a few weeks before they are carried out by gravitational settling and convection and especially rain-out. Fine particles in the upper troposphere—where there is less rainfall and where it's a longer distance to the surface—generally survive a month or two, something like that. And fine particles injected into the stratosphere where there is no rain and much less vertical convection characteristically take a year or two before they fall out. This is a very important point for the duration of the climatic effects.

More important than the dust which is put into the atmosphere is the smoke which is injected into the atmosphere from the burning of brushland and forests, but mainly from the burning of cities. Cities are a place where humans have gathered combustible material together in a very high density. Hiroshima and Nagasaki had major conflagrations from very low yield weapons. Hiroshima was about 12.6 kilotons, a yield which is called a tactical nuclear weapon today. It's not even dignified by being called a strategic weapon.

The burning of cities pumps enormous amounts of black sooty smoke into the atmosphere. That black sooty smoke is very efficient in obscuring sunlight and darkening the Earth. [Slide.]

Here are five representative nuclear war cases. We have studied something like 50 cases in which we vary not just the character of the war but also we allow uncertain parameters to vary over their plausible range.

The first is our baseline case, a 5,000-megaton war in which both countervalue and counterforce targets are hit. Countervalue for our purposes essentially means cities. You will see that only 20 percent of the yield is on urban or industrial targets. Admiral Gayler will talk later about the colocation of strategic targets with populated areas and how in any foreseeable nuclear war it is very hard to guarantee that cities will not be targeted.

Nevertheless, the second case is a case which is pure counterforce only, in which we imagine that only missile silos, hardened command posts and the like are targeted—mainly by surface bursts—and that not one city is touched. It's a very extreme and conservative case, and it will be interesting to see that even that case produces significant nuclear winter effects.

The third case I have here is in a way the opposite: only cities are targeted but with comparatively low yield. Only 100 megatons—that's less than 1 percent of the world's strategic arsenals—are expended in the burning of 100 cities.

Then the last two cases are large nuclear wars—in the 5,000 to 10,000 megaton yield range—in which the uncertain parameters are permitted to go toward the adverse end of their plausible range. [Slide.]

Now here is a graph which shows how much light gets down to the surface of the Earth as a function of time. The vertical axis is just the amount of light. The actual value in watts per square meter does not matter for our purposes here. The horizontal axis shows how long after the war we are talking about. You see we're going essentially to 1 year after the war.

If you can follow curve 1 on this graph—that's the baseline case—you will see that the light levels within a week or two after the war get down no only below that of a heavy overcast, but below what is called the compensation point for photosynthesis, the place where plants can't break even. Plants garner energy from sunlight. Plants use energy for their metabolism. There is some light level at which the plants just barely can generate enough energy to do their stuff.

Well, even in the baseline case we see that the light levels—over the entire Northern Hemisphere, I should stress—get down in the range where plants are having trouble. You can notice case 17 here, which is one of the more adverse nuclear wars, in which not only can't the plants break even, they can't do any photosynthesis at all. I stress this is not just over the targets. Immediately over the targets—over Washington let's say—it would almost certainly be pitch black. I'm talking about an average over the entire Northern Hemisphere. [Slide.]

This graph plots the surface land temperature away from coastlines as a function of time after a nuclear war. Again the curves go for almost a year into the future.

If you look at case 1, you will see that some few weeks after the war the temperature inside the major land masses of the Northern Hemisphere drop more than 30 centigrade degrees below the average value. The horizontal dashed line at the top is the ambient temperature, averaged over season, time of day, and latitude. The second horizontal line is were water freezes. You can see that curve 1 goes well below the freezing point of water and stays well below the freezing point for about 3 months. And this is part of the reason that my coauthors and I have called this phenomenon nuclear winter. Something like this would happen, we think, independent of what season the war was fought in.

And notice that curve 1 does not return to the usual values for more than a year. I want to stress that these calculations, we believe, are conservative on many different levels. We think that, when all appropriate account of every relevant factor is taken, the duration of the nuclear winter will be significantly longer than what we have indicated here. We believe that these calculations are conservative.

Second, let's take a look at case 11. That was the 3,000-megaton counterforce-only war. It is the shallowest curve on the graph. But even there the temperatures drop some 6° or 8° and I remind you of the estimate that 1° would be enough to wipe out most wheat growing in Canada. Six to eight degrees with the ancillary consequences of nuclear war—radioactivity and so on— would likely be enough to wipe out all grain production in the Northern Hemisphere at least for the duration of these effects. And the idea of a pure counterforce war in which no smoke is produced at all is obviously an extremely conservative assumption; when proper account is taken of the burning which would occur in a mainly counterforce war, the effects are still more serious than is indicated here for case 11.

Now take a look at case 14. That was the very modest nuclear war in which only cities were targeted. This is, for example, the kind of war that the French "force de frappe" is capable of fighting. The accuracy of the French strategic systems are insufficient to primarily target hardened missile silos. They can only be directed at cities, but they are adequate to burn some 100 Soviet and Eastern European cities.

Notice in that case that we have essentially the full nuclear winter effects. We get down to less than −20°C below zero.

But it recovers faster because there is no dust put up into the stratosphere.

Then, take a look at the two lower curves, the 5,000 and 10,000 megaton severe cases, and you can see that the temperatures and durations are still more serious, with extremely grave implications for life on the planet. [Slide.]

Without going into the physics of it, let me say that the absorption of sunlight in the upper atmosphere grossly distorts the temperature structure of the Earth's atmosphere. This has two consequences. One, it means that the particles stay up a lot longer than we have calculated—we assumed the atmospheric structure to be the same as it is today; and two, the hot air in the northern midlatitudes where nuclear war presumably occurs, rushes across the Equator to the colder Southern Hemisphere and this carries the fine particles with it. This is why we believe the nuclear winter is not confined to the northern midlatitudes where the war is fought, but becomes a hemisphericwide and then a global phenomenon. It appears that there are no sanctuaries in a nuclear war. [Slide.]

Here is an indication of this. I show this not because it's the best work, but because it's the first attempt at a three-dimensional global circulation model of the nuclear winter. It was done by the Soviets. This is a result of the Computing Center of the Soviet Academy of Sciences. I stress that there are results much more accurate than this, but this is more or less typical of the results available in three-dimensional models. You will notice that the temperature declines are, on the average, what we say from our one-dimensional model, although some places are colder and some places are warmer. You see here a 40° temperature decline over Iraq and Iran, which will at least slow those guys down. We must imagine the weather maps changing, of course, with time.

Just as nobody can predict weather accurately in the present kind of atmosphere, nobody can predict the weather in this atmosphere that we have not yet witnessed. But there is a major difference between predicting weather and predicting climate. We think the overall climate effects we can get to the first order rather well. Weather is a different story. [Slide.]

Now let me just very quickly indicate with a set of artist's conceptions the effects I was just talking about.

Here is the fireball from a high-yield nuclear explosion, penetrating into the stratosphere, and carrying fine dust from the surface. [Slide.]

Here you can see an artist's conceptions of a set of nuclear explosions over Florida and Cuba. [Slide.]

And here is the result of explosions in the Sinai Peninsula. Both cities and petrochemical facilities have been destroyed. The same sort of dark cloud patterns would apply if only cities were targeted. The smoke is then carried by the prevailing winds, individual plumes merge, and a dense hemisphericwide pall of sooty smoke is generated. [Slide.]

Here is a view over the Northern Hemisphere in which something like 100 nuclear weapons are shown exploding. The actual number in a 5,000-megaton nuclear war would be something like 10,000 nuclear explosions probably in a few hours.

You will notice that there are explosions both over the United States and the Soviet Union. One cannot tell from this figure who started the war. And it hardly matters. [Slide.]

Here is another Northern Hemisphere view a few days later. You can see there are several late nuclear explosions perhaps from some marine commanders who hadn't been told the war is over. You can also see a dense pall of smoke which has now circled the world, the holes in it merging. The clouds of smoke and dust have coalesced. [Slide.]

Here is now a view toward the Equator. You can see the Northern Hemisphere entirely socked in by this cloud mainly of smoke, and streamers rushing into the Southern Hemisphere. Recent findings from the National Center for Atmospheric Research in Colorado show what they call quick freezes. That is, after only a few days specific locales far removed from the war can have sudden very low temperature drops even before the main cloud makes it across the Equator. [Slide.]

Here is the artist's impression of some months after the war, in which the Southern Hemisphere is being covered over pretty much and the Northern Hemisphere is still in the cold and the dark. [Slide.]

Now these nuclear winter findings are only part of the consequences of a nuclear war. Let me remind you of some of the consequences of nuclear war. There are the prompt effects. Here, each effect is shown with a horizontal bar indicating its duration. The prompt effects at the locales of the explosions include blast, thermal radiation, prompt ionizing radiation, and fires. There is a still incompletely evaluated effect which is the production of toxic gases by the burning of modern cities. You know how when a modern skyscraper burns, people are said to have been overcome by smoke. What this is mainly is the production of toxic gases from the burning of modern synthetics. We're talking about carbon monoxide, cyanides, dioxins, furans. In the burning of modern cities there will be huge quantities of these toxic gases produced and spreading at low altitudes over the surrounding countryside.

From preliminary calculations of how much of these gases are produced, this seems to be a major effect that hasn't yet been adequately quantified.

The dark and the cold we've already talked about. Because temperatures are so low, fresh water supplies will be frozen in continental interiors away from coastlines to a depth of 6 feet or so for months.

The fallout on a time scale of months turns out to be considerably larger than has been talked about in many previous studies. That is, previous studies have concentrated on the prompt fallout and the long-term fallout attached to particles which go into the stratosphere. But fallout attached to particles that go into the upper troposphere has generally been neglected. It turns out to be significant.

In a higher-yield wars, the average whole-body dose of radiation that people get far from the target zones in the Northern Hemisphere seems to be 100 rads or more. That's enough to compromise the human immune system. The mean lethal dose for humans is somewhere around 400 rads; 100 rads for people most removed, most distant from the target zones, is something very significant, although doses around 10 rads would be comparatively harmless.

Because agriculture would collapse, and remain collapsed, at least for a time after the Sun comes out, access to food would be very limited. Massive numbers of survivors would starve to death.

Collapse of the medical system, the spread of contagious diseases, epidemics and pandemics, psychiatric disorders, and also—after the fine particles fall out—an increase in the amount of ultraviolet light at the surface that Senator Proxmire mentioned in his opening statement; all those are also expected.

Finally, there is the very vexing and difficult question of synergisms, that is, the interaction of the various effects that we have been describing.

Let me give you an example of a synergism. It gets cold. It gets dark. There's lots of radiation. Birds are especially sensitive to all three of these. Birds will die in huge numbers. Insects are much more resistant to these environmental pertubations. Many of them would just close up shop for the nuclear winter. A year or several years later, whenever conditions return more or less to normal, the insects get going. But their major predators, the birds, are dead. Therefore, there is a vast proliferation of insects.

Insects are a primary vector for disease. So disease microorganisms are spread widely over the hemisphere and over the planet. But the surviving humans have no medical care, no antisera and their immune systems have been compromised. So they are much more liable for fall sick and die.

That's an example of a synergism, the interaction of many independent effects which lead to a situation where the whole is more than the sum of the parts, I've mentioned one synergism. There must be hundreds of the sort, many of which we are insufficiently wise to have figured out. [Slide.]

Let me now come to the policy implications of nuclear winters. We have seen that the burning of 100 cities can produce a major nuclear winter and it's clear that the burning of fewer cities would still produce significant results. So it's an interesting question to ask, is there some threshold of nuclear weapons below which a nuclear war could not trigger nuclear winter? We do not know the answer to this with any precision. It's clear that one nuclear weapon will not cause nuclear winter, as the Hiroshima and Nagasaki explosions did not. We calculate that they should not have. There was not enough soot produced by those nuclear explosions to cause nuclear winter.

So provided cities are targeted, there is some threshold range in which nuclear winter could be triggered. For the sake of this discussion let us say it is somewhere between a few hundred and a few thousand nuclear weapons, provided cities are targeted. [Slide.]

Now here is a graph which shows the number of strategic weapons in the world as a function of time. There's a curve for the U.S.A. and there's a curve for the U.S.S.R. You can see the United States started out ahead in the number of nuclear weapons and has always been ahead. The gap is closing somewhat around now.

The United States crossed the threshold, the region where nuclear winter might be triggered, in the early 1950's, with nobody having a clue that that was the case. The Soviet Union crossed that threshold sometime in the middle to late 1960's, with no leader of the Soviet Union knowing of the event.

Today, if you look at the dash-dot curve which shows the sum of the U.S.A. and U.S.S.R. arsenals, there are some 18,000 strategic nuclear weapons in the world, and the number is going up sharply because of the proliferation of weapons systems and the MIRV'ing of launch vehicles. As you can see, the present level of nuclear weapons in the world is at least 10 and maybe 10's of times larger than what is needed to trigger nuclear winter. The levels of nuclear weapons in the world are vastly larger than is needed to produce this global climatic catastrophe.

The biologists who have studied this array of nuclear war effects that I have tried quickly to lay out for you--in a companion paper published in the December 23, 1983, issue of Science—conclude that this array of effects is so severe as to cause not just widespread deaths, but widespread extinctions of plants, animals, and microorganisms throughout the world. Tropical organisms, for example, are much less resistant to low temperatures than are organisms in this part of the world, because winter, ordinarily never comes in tropical latitudes.

So the biologists' paper authored by Paul Ehrlich and 19 other distinguished biologists conclude that a massive undoing of the ecology of the planet would follow from the sorts of nuclear wars we are talking about. They conclude by saying that the extinction of the human species cannot be excluded under these circumstances.

Now that is a very serious consequence. It's hard to imagine a more serious one. Extinction is the undoing of the human enterprise. It makes meaningless the lives of every human being who has ever lived and every human being who is alive today.

Now let me run through some of the implications of these results as they appear to me. I do not claim to be an expert.

Senator PROXMIRE. Mr. Sagan, I hesitate to interrupt. You're doing a magnificent job and it's so impressive, but we do have three other witnesses as you know and we have a whole series of questions we want to get into. If you can conclude in a couple of minutes, we would appreciate it very much, and I apologize because, as I say, this is one of the most impressive presentations I've heard.

Mr. SAGAN. Thank you, Senator. I will finish up in just a few minutes.

First of all, there is the possibility that first strikes are self-deterring. That is, if country A makes a first strike on country B and country B does not lift a finger to protect itself or retaliate, the cloud of smoke then travels halfway around the world back to the aggressor nation and nuclear winter falls there as well. If this is true—and it certainly seems to be—then there is a new factor in the strategic equation. The fear of first strike, which has been a major motivator of the nuclear arms race between the United States and the Soviet Union, seems to be significantly diminished.

The second implication has to do with so-called crisis relocation and civilian shelter programs. If that ever made sense, which I deeply doubt, it makes much less sense today; because of the magnitude and the duration of the effects that nuclear winter would force the survivors to pit themselves against. I think it is economically infeasible to imagine a shelter program that protects even the citizens of the United States, much less other countries, for the duration of the nuclear winter.

Third, because the effects are now global, the idea that some other nations far from the conflict might sit this war out is no longer such a great idea. Nations like Nigeria or Indonesia or Brazil might be utterly destroyed without a single nuclear weapon falling on their territory. I imagine that if these results hold up, the public concern and political pressure put by those nations on the United States and the Soviet Union will be significantly increased.

There are many implications for tactical weapons in Europe and so on, but in the interest of time I won't mention them. Let me finally just say that with anything like the present level of strategic weapons in the world, there is a wide range of circumstances in which this climatic disaster could be triggered. Were the arsenal of nuclear weapons reduced by a large factor, by a factor of 10 or 30 or something like that, deep cuts in the world arsenals, then no concatenation of computer malfunction and miscommunication and madness in high office could trigger nuclear winter.

It seems to me that living in a world in which the life of everyone depends on the sobriety and sanity of leaders, military and civilian, in many nations is betting your life on a very iffy proposition. A much safer world would be one where no concatenation of these events could trigger a nuclear winter. That means a massive cutback in the world nuclear arsenals, but it could still be adequate to preserve the posture of strategic deterrence, if that's what you want.

I consider such massive, bilateral, verifiable reductions as powerfully indicated by these findings and as simple planetary hygiene as well as elementary patriotism.

Thank you very much.

[The article entitled "Nuclear War and Climatic Catastrophe: Some Policy Implications," by Carl Sagan, follows:]

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FOREIGN
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NUCLEAR WAR AND CLIMATIC CATASTROPHE: SOME POLICY IMPLICATIONS

Carl Sagan

WINTER 1983/84 No. 62202

FOREIGN AFFAIRS

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Carl Sagan

NUCLEAR WAR AND CLIMATIC CATASTROPHE: SOME POLICY IMPLICATIONS

> It is not even impossible to imagine that the effects of an atomic war fought with greatly perfected weapons and pushed by the utmost determination will endanger the survival of man.
>
> Edward Teller
> *Bulletin of the Atomic Scientists*, February 1947

> The extreme danger to mankind inherent in the proposal by [Edward Teller and others to develop thermonuclear weapons] wholly outweighs any military advantage.
>
> J. Robert Oppenheimer, *et al.*
> *Report of the General Advisory Committee, AEC*
> October 1949

> The fact that no limits exist to the destructiveness of this weapon makes its very existence and the knowledge of its construction a danger to humanity. . . . It is . . . an evil thing.
>
> Enrico Fermi and I. I. Rabi
> Addendum, *ibid.*

> A very large nuclear war would be a calamity of indescribable proportions and absolutely unpredictable consequences, with the uncertainties tending toward the worse. . . . All-out nuclear war would mean the destruction of contemporary civilization, throw man back centuries, cause the deaths of hundreds of millions or billions of people, and, with a certain degree of probability, would cause man to be destroyed as a biological species . . .
>
> Andrei Sakharov
> *Foreign Affairs*, Summer 1983

Apocalyptic predictions require, to be taken seriously, higher standards of evidence than do assertions on other matters

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Carl Sagan is David Duncan Professor of Astronomy and Space Sciences and Director of the Laboratory for Planetary Studies at Cornell University. He has played a leading role in the Mariner, Viking and Voyager expeditions to the planets, for which he has received the NASA medals for Exceptional Scientific Achievement and (twice) for Distinguished Public Service. Study of the Martian atmosphere led to the research by Dr. Sagan and his colleagues described here. He has served as Chairman of the Division for Planetary Sciences of the American Astronomical Society; as President of the Planetology Section of the American Geophysical Union; and, for 12 years, as Editor of *Icarus*, the leading professional journal in planetary science. Dr. Sagan is also a recipient of the Peabody Award and the Pulitzer Prize.

where the stakes are not as great. Since the immediate effects of even a single thermonuclear weapon explosion are so devastating, it is natural to assume—even without considering detailed mechanisms—that the more or less simultaneous explosion of ten thousand such weapons all over the Northern Hemisphere might have unpredictable and catastrophic consequences.

And yet, while it is widely accepted that a full nuclear war might mean the end of civilization at least in the Northern Hemisphere, claims that nuclear war might imply a reversion of the human population to prehistoric levels, or even the extinction of the human species, have, among some policymakers at least, been dismissed as alarmist or, worse, irrelevant. Popular works that stress this theme, such as Nevil Shute's *On the Beach*, and Jonathan Schell's *The Fate of the Earth*, have been labeled disreputable. The apocalyptic claims are rejected as unproved and unlikely, and it is judged unwise to frighten the public with doomsday talk when nuclear weapons are needed, we are told, to preserve the peace. But, as the above quotations illustrate, comparably dire warnings have been made by respectable scientists with diverse political inclinations, including many of the American and Soviet physicists who conceived, devised and constructed the world nuclear arsenals.

Part of the resistance to serious consideration of such apocalyptic pronouncements is their necessarily theoretical basis. Understanding the long-term consequences of nuclear war is not a problem amenable to experimental verification—at least not more than once. Another part of the resistance is psychological. Most people—recognizing nuclear war as a grave and terrifying prospect, and nuclear policy as immersed in technical complexities, official secrecy and bureaucratic inertia—tend to practice what psychiatrists call denial: putting the agonizing problem out of our heads, since there seems nothing we can do about it. Even policymakers must feel this temptation from time to time. But for policymakers there is another concern: if it turns out that nuclear war could end our civilization or our species, such a finding might be considered a retroactive rebuke to those responsible, actively or passively, in the past or in the present, for the global nuclear arms race.

The stakes are too high for us to permit any such factors to influence our assessment of the consequences of nuclear war. If nuclear war now seems significantly more catastrophic than has generally been believed in the military and policy communities, then serious consideration of the resulting implications is urgently called for.

It is in that spirit that this article seeks, first, to present a short summary, in lay terms, of the climatic and biological consequences of nuclear war that emerge from extensive scientific studies conducted over the past two years, the essential conclusions of which have now been endorsed by a large number of scientists. These findings were presented in detail at a special conference in Cambridge, Mass., involving almost 100 scientists on April 22–26, 1983, and were publicly announced at a conference in Washington, D.C., on October 31 and November 1, 1983. They have been reported in summary form in the press, and a detailed statement of the findings and their bases will be published in *Science*.[1] The present summary is designed particularly for the lay reader.

Following this summary, I explore the possible strategic and policy implications of the new findings.* They point to one apparently inescapable conclusion: the necessity of moving as rapidly as possible to reduce the global nuclear arsenals below levels that could conceivably cause the kind of climatic catastrophe and cascading biological devastation predicted by the new studies. Such a reduction would have to be to a small percentage of the present global strategic arsenals.

II

The central point of the new findings is that the long-term consequences of a nuclear war could constitute a global climatic catastrophe.

The immediate consequences of a single thermonuclear weapon explosion are well known and well documented—fireball radiation, prompt neutrons and gamma rays, blast, and fires.[2] The Hiroshima bomb that killed between 100,000 and 200,000 people was a fission device of about 12 kilotons yield (the explosive equivalent of 12,000 tons of TNT). A modern thermonuclear warhead uses a device something like the Hiroshima bomb as the trigger—the "match" to light the fusion reaction. A typical thermonuclear weapon now has a yield of about 500 kilotons (or 0.5 megatons, a megaton being the explosive equivalent of a million tons of TNT). There are many weapons in the 9 to 20 megaton range in the strategic arsenals of the United States and the Soviet Union today. The highest-yield weapon ever exploded is 58 megatons.

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[1] R. P. Turco, O. B. Toon, T. P. Ackerman, J. B. Pollack and Carl Sagan [TTAPS], "Global Atmospheric Consequences of Nuclear War," *Science*, in press; P. R. Ehrlich, M. A. Harwell, Peter H. Raven, Carl Sagan, G. M. Woodwell, *et al.*, "The Long-Term Biological Consequences of Nuclear War," *Science*, in press.

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This article would not have been possible without the high scientific competence and dedication of my co-authors on the TTAPS study, Richard P. Turco, Owen B. Toon, Thomas P. Ackerman, and James B. Pollack, and my 19 coauthors of the accompanying scientific paper on the long-term biological consequences of nuclear war. Finally, I wish to thank my Soviet colleagues, V. V. Alexandrov, E. I. Chazov, G. S. Golitsyn, and E. P. Velikhov among others, for organizing independent confirmations of the probable existence of a post-nuclear-war climatic catastrophe, and for helping to generate a different kind of climate—one of mutual concern and cooperation that is essential if we are to emerge safely from the trap that our two nations have jointly set for ourselves, our civilization, and our species.

Strategic nuclear weapons are those designed for delivery by ground-based or submarine-launched missiles, or by bombers, to targets in the adversary's homeland. Many weapons with yields roughly equal to that of the Hiroshima bomb are today assigned to "tactical" or "theater" military missions, or are designated "munitions" and relegated to ground-to-air and air-to-air missiles, torpedoes, depth charges and artillery. While strategic weapons often have higher yields than tactical weapons, this is not always the case.[3] Modern tactical or theater missiles (e.g., Pershing II, SS-20) and air support weapons (e.g., those carried by F-15 or MiG-23 aircraft) have sufficient range to make the distinction between "strategic" and "tactical" or "theater" weapons increasingly artificial. Both categories of weapons can be delivered by land-based missiles, sea-based missiles, and aircraft; and by intermediate-range as well as intercontinental delivery systems. Nevertheless, by the usual accounting, there are around 18,000 strategic thermonuclear weapons (warheads) and the equivalent number of fission triggers in the American and Soviet strategic arsenals, with an aggregate yield of about 10,000 megatons.

The total number of nuclear weapons (strategic plus theater and tactical) in the arsenals of the two nations is close to 50,000, with an aggregate yield near 15,000 megatons. For convenience, we here collapse the distinction between strategic and theater weapons, and adopt, under the rubric "strategic," an aggregate yield of 13,000 megatons. The nuclear weapons of the rest of the world—

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[2] Samuel Glasstone and Philip J. Dolan, *The Effects of Nuclear War*, 3rd ed., Washington: Department of Defense, 1977.

[3] The "tactical" Pershing I, for example, is listed as carrying warheads with yields as high as 400 kilotons, while the "strategic" Poseidon C-3 is listed with a yield of only 40 kilotons. *World Armaments and Disarmament, SIPRI Yearbook 1982*, Stockholm International Peace Research Institute, London: Taylor and Francis, 1982; J. Record, *U.S. Nuclear Weapons in Europe*, Washington: Brookings Institution, 1974.

mainly Britain, France and China—amount to many hundred warheads and a few hundred megatons of additional aggregate yield.

No one knows, of course, how many warheads with what aggregate yield would be detonated in a nuclear war. Because of attacks on strategic aircraft and missiles, and because of technological failures, it is clear that less than the entire world arsenal would be detonated. On the other hand, it is generally accepted, even among most military planners, that a "small" nuclear war would be almost impossible to contain before it escalated to include much of the world arsenals.[4] (Precipitating factors include command and control malfunctions, communications failures, the necessity for instantaneous decisions on the fates of millions, fear, panic and other aspects of real nuclear war fought by real people.) For this reason alone, any serious attempt to examine the possible consequences of nuclear war must place major emphasis on large-scale exchanges in the five-to-seven-thousand-megaton range, and many studies have done so.[5] Many of the effects described below, however, can be triggered by much smaller wars.

The adversary's strategic airfields, missile silos, naval bases, submarines at sea, weapons manufacturing and storage locales, civilian and military command and control centers, attack assessment and early warning facilities, and the like are probable targets ("counterforce attack"). While it is often stated that cities are not targeted "per se," many of the above targets are very near or colocated with cities, especially in Europe. In addition, there is an industrial targeting category ("countervalue attack"). Modern nuclear doctrines require that "war-supporting" facilities be attacked. Many of these facilities are necessarily industrial in nature and engage a work force of considerable size. They are almost always situated near major transportation centers, so that raw materials and finished products can be efficiently transported to other industrial sectors, or to forces in the field. Thus, such facilities are, almost by definition, cities, or near or within cities. Other "war-supporting" targets may include the transportation systems themselves (roads, canals, rivers, railways, civilian airfields, etc.), petroleum refineries, storage sites and pipelines, hydroelectric plants, radio and television transmitters and the like. A major countervalue attack therefore might involve almost all large cities in the United States and the Soviet Union, and possibly most of the large cities in the Northern Hemisphere.[6] There are fewer than 2,500 cities in the world with populations over 100,000 inhabitants, so the devastation of all such cities is well within the means of the world nuclear arsenals.

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[4] See, e.g., D. Ball, Adelphi Paper 169, London: International Institute for Strategic Studies, 1981; P. Bracken and M. Shubik, in *Technology in Society*, Vol. 4, 1982, p. 155.

[5] National Academy of Sciences/National Research Council, *Long-term Worldwide Effects of Multiple Nuclear Weapons Detonations*, Washington: National Academy of Sciences, 1975; Office of Technology Assessment, *The Effects of Nuclear War*, Washington, 1979; J. Peterson (Ed.), *Nuclear War: The Aftermath*, special issue *Ambio*, Vol. 11, Nos. 2–3, Royal Swedish Academy of Sciences, 1982; R. P. Turco, *et al., loc. cit.* footnote 1; S. Bergstrom, *et al., Effects of Nuclear War on Health and Health Services*, Rome: World Health Organization, Publication No. A36.12, 1983; National Academy of Sciences, new 1983 study in press.

Recent estimates of the immediate deaths from blast, prompt radiation, and fires in a major exchange in which cities were targeted range from several hundred million to 1.1 billion people—the latter estimate is in a World Health Organization study in which targets were assumed not to be restricted entirely to NATO and Warsaw Pact countries.[7] Serious injuries requiring immediate medical attention (which would be largely unavailable) would be suffered by a comparably large number of people, perhaps an additional 1.1 billion.[8] Thus it is possible that something approaching half the human population on the planet would be killed or seriously injured by the direct effects of the nuclear war. Social disruption; the unavailability of electricity, fuel, transportation, food deliveries, communications and other civil services; the absence of medical care; the decline in sanitation measures; rampant disease and severe psychiatric disorders would doubtless collectively claim a significant number of further victims. But a range of additional effects—some unexpected, some inadequately treated in earlier studies, some uncovered only recently—now make the picture much more somber still.

Because of current limitations on missile accuracy, the destruction of missile silos, command and control facilities, and other hardened sites requires nuclear weapons of fairly high yield exploded as groundbursts or as low airbursts. High-yield groundbursts will vaporize, melt and pulverize the surface at the target area and propel large quantities of condensates and fine dust into the upper troposphere and stratosphere. The particles are chiefly entrained in the rising fireball; some ride up the stem of the mushroom cloud. Most military targets, however, are not very hard. The destruction of cities can be accomplished, as demonstrated at Hiroshima and Nagasaki, by lower-yield explosions less than a kilometer above the surface. Low-yield airbursts over cities or near forests will tend to produce massive fires, some of them over areas of 100,000 square kilometers or more. City fires generate enormous quantities of black oily smoke which rise at least into the upper part of the lower atmosphere, or troposphere. If firestorms occur, the smoke column rises vigorously, like the draft in a fireplace, and may carry some of the soot into the lower part of the upper atmosphere, or stratosphere. The smoke from forest and grassland fires would initially be restricted to the lower troposphere.

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[6] See, e.g., J. Peterson, *op. cit.* footnote 5.
[7] S. Bergstrom, *op. cit.* footnote 5.
[8] *Ibid.*

The fission of the (generally plutonium) trigger in every thermonuclear weapon and the reactions in the (generally uranium-238) casing added as a fission yield "booster" produce a witch's brew of radioactive products, which are also entrained in the cloud. Each such product, or radioisotope, has a characteristic "half-life" (defined as the time to decay to half its original level of radioactivity). Most of the radioisotopes have very short half-lives and decay in hours to days. Particles injected into the stratosphere, mainly by high-yield explosions, fall out very slowly—characteristically in about a year, by which time most of the fission products, even when concentrated, will have decayed to much safer levels. Particles injected into the troposphere by low-yield explosions and fires fall out more rapidly—by gravitational settling, rainout, convection, and other processes—before the radioactivity has decayed to moderately safe levels. Thus rapid fallout of tropospheric radioactive debris tends to produce larger doses of ionizing radiation than does the slower fallout of radioactive particles from the stratosphere.

Nuclear explosions of more than one-megaton yield generate a radiant fireball that rises through the troposphere into the stratosphere. The fireballs from weapons with yields between 100 kilotons and one megaton will partially extend into the stratosphere. The high temperatures in the fireball chemically ignite some of the nitrogen in the air, producing oxides of nitrogen, which in turn chemically attack and destroy the gas ozone in the middle stratosphere. But ozone absorbs the biologically dangerous ultraviolet radiation from the Sun. Thus the partial depletion of the stratospheric ozone layer, or "ozonosphere," by high-yield nuclear explosions will increase the flux of solar ultraviolet radiation at the surface of the Earth (after the soot and dust have settled out). After a nuclear war in which thousands of high-yield weapons are detonated, the increase in biologically dangerous ultraviolet light might be several hundred percent. In the more dangerous shorter wavelengths, larger increases would occur. Nucleic acids and proteins, the fundamental molecules for life on Earth, are especially sensitive to ultraviolet radiation. Thus, an increase of the solar ultraviolet flux at the surface of the Earth is potentially dangerous for life.

These four effects—obscuring smoke in the troposphere, obscuring dust in the stratosphere, the fallout of radioactive debris, and the partial destruction of the ozone layer—constitute the four known principal adverse environmental consequences that occur after a nuclear war is "over." There may be others about which we are still ignorant. The dust and, especially, the dark soot absorb ordinary visible light from the Sun, heating the atmosphere and cooling the Earth's surface.

All four of these effects have been treated in our recent scientific investigation.[9] The study, known from the initials of its authors as TTAPS, for the first time demonstrates that severe and prolonged low temperatures would follow a nuclear war. (The study also explains the fact that no such climatic effects were detected after the detonation of hundreds of megatons during the period of U.S.-Soviet atmospheric testing of nuclear weapons, ended by treaty in 1963: the explosions were sequential over many years, not virtually simultaneous; and, occurring over scrub desert, coral atolls, tundra and wasteland, they set no fires.) The new results have been subjected to detailed scrutiny, and half a dozen confirmatory calculations have now been made. A special panel appointed by the National Academy of Sciences to examine this problem has come to similar conclusions.[10]

Unlike many previous studies, the effects do not seem to be restricted to northern mid-latitudes, where the nuclear exchange would mainly take place. There is now substantial evidence that the heating by sunlight of atmospheric dust and soot over northern mid-latitude targets would profoundly change the global circulation. Fine particles would be transported across the equator in weeks, bringing the cold and the dark to the Southern Hemisphere. (In addition, some studies suggest that over 100 megatons would be dedicated to equatorial and Southern Hemisphere targets, thus generating fine particles locally.)[11] While it would be less cold and less dark at the ground in the Southern Hemisphere than in the Northern, massive climatic and environmental disruptions may be triggered there as well.

In our studies, several dozen different scenarios were chosen, covering a wide range of possible wars, and the range of uncertainty in each key parameter was considered (e.g., to describe how many fine particles are injected into the atmosphere). Five representative cases are shown in Table 1, below, ranging from a small low-yield attack exclusively on cities, utilizing, in yield, only 0.8 percent of the world strategic arsenals, to a massive exchange involving 75

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[9] R. P. Turco, *et al.*, *loc. cit.* footnote 1.

[10] National Academy of Sciences, 1983, *loc. cit.* footnote 5.

[11] J. Peterson, *op. cit.* footnote 6.

TABLE 1

NUCLEAR EXCHANGE SCENARIOS

Case	Total Yield (MT)	% Yield Surface Bursts	% Yield Urban or Industrial Targets	Warhead Yield Range (MT)	Total Number of Explosions
1. Baseline Case, countervalue and counterforce[a]	5,000	57	20	0.1–10	10,400
11. 3,000 MT nominal, counterforce only[b]	3,000	50	0	1 –10	2,250
14. 100 MT nominal, countervalue only[c]	100	0	100	0.1	1,000
16. 5000 MT "severe," counterforce only[b,d]	5,000	100	0	5 –10	700
17. 10,000 MT "severe," countervalue and counterforce[c,d]	10,000	63	15	0.1–10	16,160

a. In the Baseline Case, 12,000 square kilometers of inner cities are burned; on every square centimeter an average of 10 grams of combustibles are burned, and 1.1% of the burned material rises as smoke. Also, 230,000 square kilometers of suburban areas burn, with 1.5 grams consumed at each square centimeter and 3.6% rising as smoke.

b. In this highly conservative case, it is assumed that no smoke emission occurs, that not a blade of grass is burned. Only 25,000 tons of the fine dust is raised into the upper atmosphere for every megaton exploded.

c. In contrast to the Baseline Case, only inner cities burn, but with 10 grams per square centimeter consumed and 3.3% rising as smoke into the high atmosphere.

d. Here, the fine (submicron) dust raised into the upper atmosphere is 150,000 tons per megaton exploded.

percent of the world arsenals. "Nominal" cases assume the most probable parameter choices; "severe" cases assume more adverse parameter choices, but still in the plausible range.

Predicted continental temperatures in the Northern Hemisphere vary after the nuclear war according to the curves shown in Figure 1 on the following page. The high heat-retention capacity of water guarantees that oceanic temperatures will fall at most by a few degrees. Because temperatures are moderated by the adjacent oceans, temperature effects in coastal regions will be less extreme than in continental interiors. The temperatures shown in Figure 1 are average values for Northern Hemisphere land areas.

Even much smaller temperature declines are known to have serious consequences. The explosion of the Tambora volcano in Indonesia in 1815 led to an average global temperature decline of only 1°C, due to the obscuration of sunlight by the fine dust propelled into the stratosphere; yet the hard freezes the following year were so severe that 1816 has been known in Europe and America as "the year without a summer." A 1°C cooling would

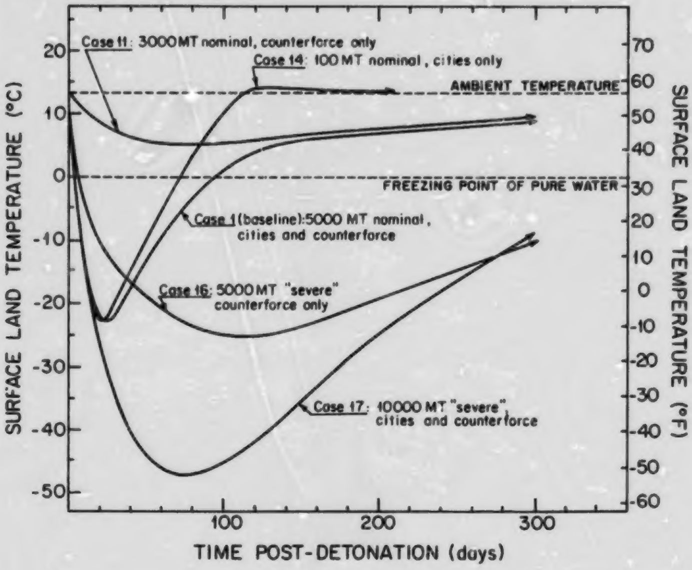

FIGURE 1

TEMPERATURE EFFECTS OF NUCLEAR WAR CASES

NOTE: In this Figure, the average temperature of Northern Hemisphere land areas (away from coastlines) is shown varying with time after the five Cases of nuclear war defined in Table 1. The "ambient" temperature is the average in the Northern Hemisphere over all latitudes and seasons: thus, normal winter temperatures at north temperature latitudes are lower than is shown, and normal tropical temperatures are higher than shown. Cases described as "nominal" assume the most likely values of parameters (such as dust particle size or the frequency of firestorms) that are imperfectly known. Cases marked "severe" represent adverse but not implausible values of these parameters. In Case 14 the curve ends when the temperatures come within a degree of the ambient values. For the four other Cases the curves are shown ending after 300 days, but this is simply because the calculations were not extended further. In these four Cases the curves will continue to the directions they are headed.

nearly eliminate wheat growing in Canada.[12] In the last thousand years, the maximum global or Northern Hemisphere temperature deviations have been around 1°C. In an Ice Age, a typical long-term temperature decline from preexisting conditions is about 10°C. Even the most modest of the cases illustrated in Figure 1 give temporary temperature declines of this order. The Baseline Case is much more adverse. Unlike the situation in an Ice Age, however, the global temperatures after nuclear war plunge rapidly and take only months to a few years to recover, rather than thousands of years. No new Ice Age is likely to be induced by a Nuclear Winter.

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[12] National Academy of Sciences, 1975, *op. cit.* footnote 5.

Because of the obscuration of the Sun, the daytime light levels can fall to a twilit gloom or worse. For more than a week in the northern mid-latitude target zone, it might be much too dark to see, even at midday. In Cases 1 and 14 (Table 1), hemispherically averaged light levels fall to a few percent of normal values, comparable to those at the bottom of a dense overcast. At this illumination, many plants are close to what is called the compensation point, the light level at which photosynthesis can barely keep pace with plant metabolism. In Case 17, illumination, averaged over the entire Northern Hemisphere, falls in daytime to about 0.1 percent of normal, a light level at which plants will not photosynthesize at all. For Cases 1 and especially 17, full recovery to ordinary daylight takes a year or more (Figure 1).

As the fine particles fall out of the atmosphere, carrying radioactivity to the ground, the light levels increase and the surface warms. The depleted ozone layer now permits ultraviolet light to reach the Earth's surface in increased proportions. The relative timing of the multitude of adverse consequences of a nuclear war is shown in Table 2, on the following page.

Perhaps the most striking and unexpected consequence of our study is that even a comparatively small nuclear war can have devastating climatic consequences, provided cities are targeted (see Case 14 in Figure 1; here, the centers of 100 major NATO and Warsaw Pact cities are burning). There is an indication of a very rough threshold at which severe climatic consequences are triggered—around a few hundred nuclear explosions over cities, for smoke generation, or around 2,000 to 3,000 high-yield surface bursts at, e.g., missile silos, for dust generation and ancillary fires. Fine particles can be injected into the atmosphere at increasing rates with only minor effects until these thresholds are crossed. Thereafter, the effects rapidly increase in severity.[13]

As in all calculations of this complexity, there are uncertainties. Some factors tend to work towards more severe or more prolonged effects; others tend to ameliorate the effects.[14] The detailed TTAPS calculations described here are one-dimensional; that is, they assume the fine particles to move vertically by all the appropriate

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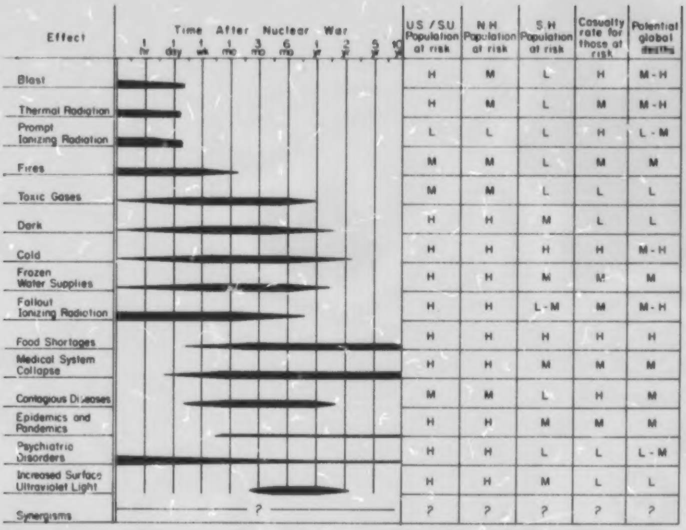
[13] The climatic threshold for smoke in the troposphere is about 100 million metric tons, injected essentially all at once; for sub-micron fine dust in the stratosphere, about the same.

[14] The slow warming of the Earth due to a CO_2 greenhouse effect attendant to the burning of fossil fuels should not be thought of as tempering the nuclear winter: the greenhouse temperature increments are too small and too slow.


Time After Nuclear War
1 hr
1 day
1 wk
1 mo
3 mo
6 mo
1 yr
2 yr
5 yr
10 yr

Effect	Time After Nuclear War	US / S.U Population at risk	N H Population at risk	S H Population at risk	Casualty rate for those at risk	Potential global deaths
Blast		H	M	L	H	M - H
Thermal Radiation		H	M	L	M	M - H
Prompt Ionizing Radiation		L	L	L	H	L - M
Fires		M	M	L	M	M
Toxic Gases		M	M	L	L	L
Dark		H	H	M	L	L
Cold		H	H	H	H	M - H
Frozen Water Supplies		H	H	M	M	M
Fallout Ionizing Radiation		H	H	L - M	M	M - H
Food Shortages		H	H	H	H	H
Medical System Collapse		H	H	M	M	M
Contagious Diseases		M	M	L	H	M
Epidemics and Pandemics		H	H	M	M	M
Psychiatric Disorders		H	H	L	L	L - M
Increased Surface Ultraviolet Light		H	H	M	L	L
Synergisms	?	?	?	?	?	?

TABLE 2

EFFECTS OF THE BASELINE NUCLEAR WAR

NOTE: This is a schematic representation of the time scale for the effects, which are most severe when the thickness of the horizontal bar is greatest. The columns at the right indicate the degree of risk of the populations of the United States and the Soviet Union, the Northern Hemisphere, and the Southern Hemisphere--with H, M, and L standing for High, Medium, and Low respectively.

laws of physics, but neglect the spreading in latitude and longitude. When soot or dust is moved away from the reference locale, things get better there and worse elsewhere. In addition, fine particles can be transported by weather systems to other locales, where they are carried more rapidly down to the surface. That would ameliorate obscuration not just locally but globally. It is just this transport away from the northern mid-latitudes that involves the equatorial zone and the Southern Hemisphere in the effects of the nuclear war. It would be helpful to perform an accurate three-dimensional calculation on the general atmospheric circulation following a nuclear war. Preliminary estimates suggest that circulation might moderate the low temperatures in the Northern Hemisphere predicted in our calculations by some 30 percent, lessening somewhat the severity of the effects, but still leaving them at catastrophic levels (e.g., a 30°C rather than a 40°C temperature drop). To provide a small margin of safety, we neglect this correction in our subsequent discussion.

There are also effects that tend to make the results much worse: for example, in our calculations we assumed that rainout of fine particles occurred through the entire troposphere. But under realistic circumstances, at least the upper troposphere may be very dry, and any dust or soot carried there initially may take much longer to fall out. There is also a very significant effect deriving from the drastically altered structure of the atmosphere, brought about by the heating of the clouds and the cooling of the surface. This produces a region in which the temperature is approximately constant with altitude in the lower atmosphere and topped by a massive temperature inversion. Particles throughout the atmosphere would then be transported vertically very slowly—as in the present stratosphere. This is a second reason why the lifetime of the clouds of soot and dust may be much longer than we have calculated. If so, the worst of the cold and the dark might be prolonged for considerable periods of time, conceivably for more than a year. We also neglect this effect in subsequent discussion.

Nuclear war scenarios are possible that are much worse than the ones we have presented. For example, if command and control capabilities are lost early in the war—by, say, "decapitation" (an early surprise attack on civilian and military headquarters and communications facilities)—then the war conceivably could be extended for weeks as local commanders make separate and uncoordinated decisions. At least some of the delayed missile launches could be retaliatory strikes against any remaining adversary cities. Generation of an additional smoke pall over a period of weeks or longer following the initiation of the war would extend the magnitude, but especially the duration of the climatic consequences. Or it is possible that more cities and forests would be ignited than we have assumed, or that smoke emissions would be larger, or that a greater fraction of the world arsenals would be committed. Less severe cases are of course possible as well.

These calculations therefore are not, and cannot be, assured prognostications of the full consequences of a nuclear war. Many refinements in them are possible and are being pursued. But there is general agreement on the overall conclusions: in the wake of a nuclear war there is likely to be a period, lasting at least for months, of extreme cold in a radioactive gloom, followed—after the soot and dust fall out—by an extended period of increased ultraviolet light reaching the surface.[15]

We now explore the biological impact of such an assault on the global environment.

III

The immediate human consequences of nuclear explosions range from vaporization of populations near the hypocenter, to blast-generated trauma (from flying glass, falling beams, collapsing skyscrapers and the like), to burns, radiation sickness, shock and severe psychiatric disorders. But our concern here is with longer-term effects.

It is now a commonplace that in the burning of modern tall buildings, more people succumb to toxic gases than to fire. Ignition of many varieties of building materials, insulation and fabrics generates large amounts of such pyrotoxins, including carbon monoxide, cyanides, vinyl chlorides, oxides of nitrogen, ozone, dioxins, and furans. Because of differing practices in the use of such synthetics, the burning of cities in North America and Western Europe will probably generate more pyrotoxins than cities in the Soviet Union, and cities with substantial recent construction more than older, unreconstructed cities. In nuclear war scenarios in which a great many cities are burning, a significant pyrotoxin smog might persist for months. The magnitude of this danger is unknown.

The pyrotoxins, low light levels, radioactive fallout, subsequent ultraviolet light, and especially the cold are together likely to destroy almost all of Northern Hemisphere agriculture, even for the more modest Cases 11 and 14. A 12° to 15°C temperature reduction by itself would eliminate wheat and corn production in the United States, even if all civil systems and agricultural technology were intact.[16] With unavoidable societal disruption, and with the other environmental stresses just mentioned, even a 3,000-megaton "pure" counterforce attack (Case 11) might suffice. Realistically, many fires would be set even in such an attack (see below), and a 3,000-megaton war is likely to wipe out U.S. grain production. This would represent by itself an unprecedented global catastrophe: North American grain is the principal reliable source of export food on the planet, as well as an essential component of U.S. prosperity. Wars just before harvesting of grain and other staples would be incrementally worse than wars after harvesting. For many scenarios, the effects will extend (see Figure 2) into two or more growing seasons. Widespread fires and subsequent runoff of topsoil are among the many additional deleterious consequences extending for years after the war.

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[15] These results are dependent on important work by a large number of scientists who have previously examined aspects of this subject; many of these workers are acknowledged in the articles cited in footnote 1.

[16] David Pimentel and Mark Sorrells, private communication, 1983.

Something like three-quarters of the U.S. population lives in or near cities. In the cities themselves there is, on average, only about one week's supply of food. After a nuclear war it is conceivable that enough of present grain storage might survive to maintain, on some level, the present population for more than a year. But with the breakdown of civil order and transportation systems in the cold, the dark and the fallout, these stores would become largely inaccessible. Vast numbers of survivors would soon starve to death.

In addition, the sub-freezing temperatures imply, in many cases, the unavailability of fresh water. The ground will tend to be frozen to a depth of about a meter—incidentally making it unlikely that the hundreds of millions of dead bodies would be buried, even if the civil organization to do so existed. Fuel stores to melt snow and ice would be in short supply, and ice surfaces and freshly fallen snow would tend to be contaminated by radioactivity and pyrotoxins.

In the presence of excellent medical care, the average value of the acute lethal dose of ionizing radiation for healthy adults is about 450 rads. (As with many other effects, children, the infirm and the elderly tend to be more vulnerable.) Combined with the other assaults on survivors in the postwar environment, and in the probable absence of any significant medical care, the mean lethal acute dose is likely to decline to 350 rads or even lower. For many outdoor scenarios, doses within the fallout plumes that drift hundreds of kilometers downwind of targets are greater than the mean lethal dose. (For a 10,000-megaton war, this is true for more than 30 percent of northern mid-latitude land areas.) Far from targets, intermediate-timescale chronic doses from delayed radioactive fallout may be in excess of 100 rads for the baseline case. These calculations assume no detonations on nuclear reactors or fuel-reprocessing plants, which would increase the dose.

Thus, the combination of acute doses from prompt radioactive fallout, chronic doses from the delayed intermediate-timescale fallout, and internal doses from food and drink are together likely to kill many more by radiation sickness. Because of acute damage to bone marrow, survivors would have significantly increased vulnerability to infectious diseases. Most infants exposed to 100 rads as fetuses in the first two trimesters of pregnancy would suffer mental retardation and/or other serious birth defects. Radiation and some pyrotoxins would later produce neoplastic diseases and genetic damage. Livestock and domesticated animals, with fewer resources, vanishing food supplies and in many cases with greater sensitivity to the stresses of nuclear war than human beings, would also perish in large numbers.

These devastating consequences for humans and for agriculture would not be restricted to the locales in which the war would principally be "fought," but would extend throughout northern mid-latitudes and, with reduced but still significant severity, probably to the tropics and the Southern Hemisphere. The bulk of the world's grain exports originate in northern mid-latitudes. Many nations in the developing as well as the developed world depend on the import of food. Japan, for example, imports 75 percent of its food (and 99 percent of its fuel). Thus, even if there were no climatic and radiation stresses on tropical and Southern Hemisphere societies—many of them already at subsistence levels of nutrition—large numbers of people there would die of starvation.

As agriculture breaks down worldwide (possible initial exceptions might include Argentina, Australia and South Africa if the climatic impact on the Southern Hemisphere proved to be minimal), there will be increasing reliance on natural ecosystems--fruits, tubers, roots, nuts, etc. But wild foodstuffs will also have suffered from the effects of the war. At just the moment that surviving humans turn to the natural environment for the basis of life, that environment would be experiencing a devastation unprecedented in recent geological history.

Two-thirds of all species of plants, animals, and microorganisms on the Earth live within 25° of the equator. Because temperatures tend to vary with the seasons only minimally at tropical latitudes, species there are especially vulnerable to rapid temperature declines. In past major extinction events in the paleontological record, there has been a marked tendency for tropical organisms to show greater vulnerability than organisms living at more temperate latitudes.

The darkness alone may cause a collapse in the aquatic food chain in which sunlight is harvested by phytoplankton, phytoplankton by zooplankton, zooplankton by small fish, small fish by large fish, and, occasionally, large fish by humans. In many nuclear war scenarios, this food chain is likely to collapse at its base for at least a year and is significantly more imperiled in tropical waters. The increase in ultraviolet light available at the surface of the earth approximately a year after the war provides an additional major environmental stress that by itself has been described as having "profound consequences" for aquatic, terrestrial and other ecosystems.[17]

The global ecosystem can be considered an intricately woven fabric composed of threads contributed by the millions of separate species that inhabit the planet and interact with the air, the water and the soil. The system has developed considerable resiliency, so that pulling a single thread is unlikely to unravel the entire fabric. Thus, most ordinary assaults on the biosphere are unlikely to have catastrophic consequences. For example, because of natural small changes in stratospheric ozone abundance, organisms have probably experienced, in the fairly recent geologic past, ten percent fluctuations in the solar near-ultraviolet flux (but not fluctuations by factors of two or more). Similarly, major continental temperature changes of the magnitude and extent addressed here may not have been experienced for tens of thousands and possibly not for millions of years. We have no experimental information, even for aquaria or terraria, on the simultaneous effects of cold, dark, pyrotoxins, ionizing radiation, and ultraviolet light as predicted in the TTAPS study.

Each of these factors, taken separately, may carry serious consequences for the global ecosystem: their interactions may be much more dire still. Extremely worrisome is the possibility of poorly understood or as yet entirely uncontemplated synergisms (where the net consequences of two or more assaults on the environment are much more than the sum of the component parts). For example, more than 100 rads (and possibly more than 200 rads) of external and ingested ionizing radiation is likely to be delivered in a very large nuclear war to all plants, animals and unprotected humans in densely populated regions of northern mid-latitudes. After the soot and dust clear, there can, for such wars, be a 200 to 400 percent increment in the solar ultraviolet flux that reaches the ground, with an increase of many orders of magnitude in the more dangerous shorter-wavelength radiation. Together, these radiation assaults are likely to suppress the immune systems of humans and other species, making them more vulnerable to disease. At the same time, the high ambient-radiation fluxes are likely to produce, through mutation, new varieties of microorganisms, some of which might become pathogenic. The preferential radiation sensitivity of birds and other insect predators would enhance the proliferation of herbivorous and pathogen-carrying insects. Carried by vectors with high radiation tolerance, it seems possible that epidemics and global pandemics would propagate with no hope of effective mitigation by medical care, even with reduced population sizes and greatly restricted human mobility. Plants, weakened by low temperatures and low light levels, and other animals would likewise be vulnerable to preexisting and newly arisen pathogens.

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[17] C. H. Kruger, R. B. Setlow, *et al.*, *Causes and Effects of Stratospheric Ozone Reduction: An Update*, Washington: National Academy of Sciences, 1982.

There are many other conceivable synergisms, all of them still poorly understood because of the complexity of the global ecosystem. Every synergism represents an additional assault, of unknown magnitude, on the global ecosystem and its support functions for humans. What the world would look like after a nuclear war depends in part upon the unknown synergistic interaction of these various adverse effects.

We do not and cannot know that the worst would happen after a nuclear war. Perhaps there is some as yet undiscovered compensating effect or saving grace—although in the past, the overlooked effects in studies of nuclear war have almost always tended toward the worst. But in an uncertain matter of such gravity, it is wise to contemplate the worst, especially when its probability is not extremely small. The summary of the findings of the group of 40 distinguished biologists who met in April 1983 to assess the TTAPS conclusions is worthy of careful consideration:[18]

> Species extinction could be expected for most tropical plants and animals, and for most terrestrial vertebrates of north temperate regions, a large number of plants, and numerous freshwater and some marine organisms. . . . Whether any people would be able to persist for long in the face of highly modified biological communities; novel climates; high levels of radiation; shattered agricultural, social, and economic systems; extraordinary psychological stresses; and a host of other difficulties is open to question. It is clear that the ecosystem effects *alone* resulting from a large-scale thermonuclear war could be enough to destroy the current civilization in at least the Northern Hemisphere. Coupled with the direct casualties of perhaps two billion people, the combined intermediate and long-term effects of nuclear war suggest that eventually there might be no human survivors in the Northern Hemisphere.
>
> Furthermore, the scenario described here is by no means the most severe that could be imagined with present world nuclear arsenals and those contemplated for the near future. In almost any realistic case involving nuclear exchanges between the superpowers, global environmental changes sufficient to cause an extinction event equal to or more severe than that at the close of the Cretaceous when the dinosaurs and many other species died out are likely. In that event, the possibility of the extinction of *Homo sapiens* cannot be excluded.

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[18] P. Ehrlich, *et al.*, *loc. cit.* footnote 1.

IV

The foregoing probable consequences of various nuclear war scenarios have implications for doctrine and policy. Some have argued that the difference between the deaths of several hundred million people in a nuclear war (as has been thought until recently to be a reasonable upper limit) and the death of every person on Earth (as now seems possible) is only a matter of one order of magnitude. For me, the difference is considerably greater. Restricting our attention only to those who die as a consequence of the war conceals its full impact.

If we are required to calibrate extinction in numerical terms, I would be sure to include the number of people in future generations who would not be born. A nuclear war imperils all of our descendants, for as long as there will be humans. Even if the population remains static, with an average lifetime of the order of 100 years, over a typical time period for the biological evolution of a successful species (roughly ten million years), we are talking about some 500 trillion people yet to come. By this criterion, the stakes are one million times greater for extinction than for the more modest nuclear wars that kill "only" hundreds of millions of people.

There are many other possible measures of the potential loss—including culture and science, the evolutionary history of the planet, and the significance of the lives of all of our ancestors who contributed to the future of their descendants. Extinction is the undoing of the human enterprise.

For me, the new results on climatic catastrophe raise the stakes of nuclear war enormously. But I recognize that there are those, including some policymakers, who feel that the increased level of fatalities has little impact on policy, but who nevertheless acknowledge that the newly emerging consequences of nuclear war may require changes in specific points of strategic doctrine. I here set down what seem to me some of the more apparent such implications, within the context of present nuclear stockpiles. The idea of a crude threshold, very roughly around 500 to 2,000 warheads, for triggering the climatic catastrophe will be central to some of these considerations. (Such a threshold applies only to something like the present distribution of yields in the strategic arsenals. Drastic conversion to very low-yield arsenals—see below—changes some of the picture dramatically.) I hope others will constructively examine these preliminary thoughts and explore additional implications of the TTAPS results.

1. *First Strike.* The MIRVing of missiles (the introduction of mul-

tiple warheads), improvements in accuracy, and other developments have increased the perceived temptation to launch a devastating first strike against land targets—even though both sides retain a powerful retaliatory force in airborne bombers and submarines at sea. Much current concern and national rhetoric is addressed to the first-strike capability of extant or proposed weapons systems. The mere capability of a first strike creates incentives for a preemptive attack. Launch-on-warning and simultaneous release of all strategic weapons are two of several ominous and destabilizing innovations contrived in response to the fear of a first strike.

The number of U.S. land-based strategic missiles is about 1,050; for the Soviet Union, about 1,400. In addition, each side has at least several dozen dedicated and alternative strategic bomber bases and airstrips, as well as command and control facilities, submarine ports and other prime strategic targets on land. Each target requires—for high probability of its destruction—two or perhaps three attacking warheads. Thus, a convincing first strike against land targets requires at least 2,200 and perhaps as many as 4,500 attacking warheads. Some—for example, to disable bombers that succeed in becoming airborne just before the first strike—would detonate as airbursts. While many missile silos, especially in the United States, are surrounded by farmland and brush, other strategic targets, especially in Europe and Asia, are sufficiently near forests or urban areas for major conflagrations to be set, even in a "pure" counterforce attack. Accordingly, a major first strike would be clearly in the vicinity of, and perhaps well over, the climatic threshold.

A counterforce first strike is unlikely to be completely effective. Perhaps 10 to 40 percent of the adversary's silos and most of its airborne bombers and submarines at sea will survive, and *its* response may not be against silos, but against cities. Ten percent of a 5,000-warhead strategic arsenal is 500 warheads: distributed over cities, this seems by itself enough to trigger a major climatic catastrophe.

Such a first strike scenario, in which the danger to the aggressor nation depends upon the unpredictable response of the attacked nation, seems risky enough. (The hope for the aggressor nation is that its retained second-strike force, including strategic submarines and unlaunched land-based missiles, will intimidate the adversary into surrender rather than provoke it into retaliation.) But the decision to launch a first strike that is tantamount to national suicide for the aggressor—*even if the attacked nation does not lift a finger to retaliate*—is a different circumstance altogether. If a first strike gains no more than a pyrrhic victory of ten days' duration before the prevailing winds carry the nuclear winter to the aggressor nation, the "attractiveness" of the first strike would seem to be diminished significantly.

A Doomsday Machine is useless if the potential adversary is ignorant of its presence.[19] But since many distinguished scientists, both American and Soviet, have participated vigorously in recent studies of the climatic consequences of nuclear war, since there appears to be no significant disagreement in the conclusions, and since policymakers will doubtless be apprised of these new results, it would appear that a decision to launch a major first strike is now much less rational, and therefore, perhaps, much less probable. The better political leaders understand the nuclear winter, the more secure are such conclusions.

If true, this should have cascading consequences for specific weapons systems. Further, the perceived vulnerability to a first strike has been a major source of stress and fear, and thereby a major spur to the nuclear arms race. Knowledge that a first strike is now less probable might make at least some small contribution to dissipating the poisonous atmosphere of mistrust that currently characterizes Soviet-American relations.

2. *Sub-threshold War.* Devastating nuclear wars that are nevertheless significantly below the threshold for severe climatic consequences certainly seem possible—for example, the destruction of 10 or 20 cities, or 100 silos of a particularly destabilizing missile system. Nevertheless, might some nation be tempted to initiate or engage in a much larger, but still reliably sub-threshold nuclear war? The hope might be that the attacked adversary would be reluctant to retaliate for fear of crossing the threshold.

This is not very different from the hope that a counterforce first strike would not be followed by a retaliatory strike, because of the aggressor's retention of an invulnerable (for example, submarine-based) second-strike force adequate to destroy populations and national economies. It suffers the same deficiency—profound uncertainty about the likely response.

The strategic forces of the United States or the Soviet Union—even if they were all at fixed sites—could not be destroyed in a reliably sub-threshold war: there are too many essential targets. Thus, a sub-threshold first strike powerfully provokes the attacked nation and leaves much of its retaliatory force untouched. It is easy to imagine a nation, having contemplated becoming the object of a sub-threshold first strike, planning to respond in kind, because it judges that failure to do so would itself invite attack. Retaliation could occur immediately against a few key cities—if national leaders were restrained and command and control facilities intact—or massively, months later, after much of the dust and smoke have fallen out, extending the duration but ameliorating the severity of the net climatic effects.

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[19] The term "Doomsday Machine" is due to Herman Kahn, *Thinking About the Unthinkable*, New York: Horizon Press, 1962.

This, however, may not be the case for such nations as Britain, France or China. Because of the marked contiguity of strategic targets and urban areas in Europe, the climatic threshold for attacks on European nuclear powers may be significantly less than for the United States or the Soviet Union. Provided it could be accomplished without triggering a U.S.-Soviet nuclear war, first strikes against all the fixed-site strategic forces of one of these nations might not trigger the climatic catastrophe. Nevertheless, the invulnerable retaliatory capability of these nations—especially the ballistic-missile submarines of Britain and France—makes such a first strike unlikely.

3. *Treaties on Yields and Targeting.* I would not include this possibility, except that it has been mentioned publicly by a leading American nuclear strategist. The proposal has two parts. The first is to ban by treaty all nuclear warheads with yields in excess of 300 or 400 kilotons. The fireballs from warheads of higher yields mainly penetrate into the stratosphere and work to deplete the ozonosphere.

The reconversion of nuclear warheads to lower individual yields would reduce (although not remove) the threat of significantly enhanced ultraviolet radiation at the surface of the Earth, but would in itself have no bearing on the issue of climatic catastrophe, and would increase the intermediate-timescale radioactive fallout. Within the present strategic arsenals, there is no mix of yields that simultaneously minimizes ionizing radiation from fallout and ultraviolet radiation from the Sun.

As delivery system accuracy has progressively improved, there has been a corresponding tendency toward the deployment of lower-yield warheads, although not through any concern about the integrity of the ozonosphere. There is also a trend toward higher fission fractions, implying more radioactive fallout. Limitations on the sizes and therefore, to some extent, on the yields of new warheads are part of recent U.S. arms control proposals. With the bulk of Soviet strategic warheads having yields larger than their U.S. counterparts, however, treaties limiting high yields place greater demands on Soviet than on U.S. compliance. Moreover, to enforce a categorical yield ceiling seems to imply verification problems of some difficulty.

The second part of the proposal is to guarantee by treaty that cities would not be targeted. Then the worst of the climatic effects might be avoided, although the climatic consequences of "pure" counterforce exchanges can still be extremely serious (Figure 1). The encoding of targeting coordinates, however, is in principle done remotely, and involves different coordinates for each warhead. Even if we could imagine international inspection teams descending unannounced on Soviet or American missile silos to inspect the targeting coordinates, an hour later the coordinates could be returned to those appropriate for cities.

Targeting policy is among the most sensitive aspects of nuclear strategy, and maintaining uncertainty about targeting policy is thought to be an essential component of U.S. deterrence. The proposal is unlikely to be received warmly by the U.S. Joint Strategic Targeting Staff or its Soviet counterpart. It is also difficult to understand how those skeptical of the verifiability by reconnaissance satellites of SALT II provisions on the deployment of missiles ten meters long can rest easy about verification of treaties controlling what is encoded in a microchip one millimeter long. Nevertheless, a symbolic, unverifiable targeting treaty, entered into because both sides recognize that it is not in their interest to target cities, might have some merit.

4. *Transition to Low-Yield High-Accuracy Arsenals.* A conceivable response to the prospect of climatic catastrophe might be to continue present trends toward lower-yield and higher-accuracy missiles, perhaps accompanied by development of the technology for warheads to burrow sub-surface before detonating. Payloads have been developed for the Pershing II missile that use radar area-correlators for target recognition and terminal guidance; the targeting probable error is said to be 40 meters.[20] It is evident that a technology is gradually emerging that could permit delivery accuracies of 35 meters or better over intercontinental ranges.

It is evident as well that burrowing technology is also under rapid development.[21] A one-kiloton burst, two to three meters sub-surface, will excavate a crater roughly 60 meters across.[22] Clearly, high-accuracy penetrating warheads in the one-to-ten-kiloton range would be able, with high reliability, to destroy even very hardened silos and underground command posts.

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[20] *Aviation Week and Space Technology*, May 15, 1978, p. 225.

[21] *Ibid.*

[22] S. Glasstone and P. J. Dolan, *op. cit.* footnote 2.

Low-yield sub-surface explosions of this sort cannot threaten the ozonosphere. They minimize fires, soot, stratospheric dust and radioactive fallout. Even several thousand simultaneous such detonations might not trigger the nuclear winter. Similar technology might be used for pinpoint attacks on military/industrial targets in urban areas. Thus, the TTAPS results will probably lead to calls for further improvements in high-accuracy earth-burrowing warheads.

There are, I think, a number of difficulties with this proposal, as attractive as it seems in a strictly military context. A world in which the nuclear arsenals were completely converted to a relatively small number of burrowing low-yield warheads would be much safer in terms of the climatic catastrophe. But such warheads are provocative. They are the perfect post-TTAPS first-strike weapon. Their development might well be taken as a serious interest in making a climatically safe but disabling first strike. Greatly expanded deployment of anti-ballistic missiles might be one consequence of their buildup.

Retaliation from surviving silos, aircraft and especially submarines, as discussed above, is likely, whatever the disposition of yields in a first strike. Also, arsenals cannot be converted instantaneously. There would be a very dangerous and protracted transition period in which enough newer weapons are deployed to be destabilizing, and enough older weapons are still in place to trigger the nuclear winter.

However, if the inventories of modern higher-yield (more than ten kiloton) warheads were first brought below threshold, a coordinated U.S.-Soviet deployment of low-yield burrowers might be accomplished in somewhat greater safety. On many launchers, each with a single warhead, they might provide a useful reassurance to defense ministries at some points in the transition process. At any rate, the dramatic reduction of arsenals necessary to go below threshold before large-scale burrower deployment is indistinguishable from major arms reduction for its own sake (see below).

5. *Consequences for the Developing World.* Before the TTAPS calculations were performed, it was possible to argue that the developing world would be severely affected by secondary economic consequences, but not fundamentally destroyed by a northern mid-latitude nuclear war. Now it seems more likely that nations having no part in the conflict—even nations entirely neutral in the global confrontation between the United States and the Soviet Union—might be reduced to prehistoric population levels and economies, or worse. Nations between 70°N and 30°S, nations with marginal economies, nations with large food imports or extensive malnutri-

tion today, and nations with their own strategic targets are particularly at risk.

Thus, the very survival of nations distant from any likely nuclear conflict can now be seen to depend on the prudence and wisdom of the major nuclear powers. India, Brazil, Nigeria or Saudi Arabia could collapse in a nuclear war without a single bomb being dropped on their territories.[23]

Quite apart from any concern about the deflection of world financial, technical and intellectual resources to the nuclear arms race, the prospect of nuclear war now clearly and visibly threatens every nation and every person on the planet. The diplomatic and economic pressure accordingly placed on the five nuclear powers by the other nations of the world, concerned about their own survival, could be at least marginally significant.

6. *Shelters.* The usual sorts of shelters envisioned for civilian populations are ineffective even for the nuclear war consequences known before the TTAPS study. The more ambitious among them include food and water for a week or two, modest heating capabilities, rudimentary sanitary and air filtration facilities and no provisions for the psychological burdens of an extended stay below ground with unknown climatic and ecological consequences propagating overhead. The kinds of shelters suitable for prolonged subfreezing temperatures, high radiation doses, and pyrotoxins would have to be very much more elaborate—quite apart from the question of what good it would be to emerge six or nine months later to an ultraviolet-bathed and biologically depauperate surface, with insect pests proliferating, disease rampant, and the basis of agriculture destroyed.

Appropriate shelters, able to service individual families or family groups for months to a year, are too expensive for most families even in the affluent West. The construction of major government shelters for civilian populations would be enormously expensive as well as in itself potentially destabilizing. The prospect of the climatic catastrophe also heightens the perceived inequity between government leaders and (in some cases) their families, provided elaborate shelters, and the bulk of the civilian population, unable to afford even a minimally adequate shelter.

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[23] The distribution of the coldest regions will vary with time and geography. In one recent but still very crude three-dimensional simulation of the nuclear winter, the temperature has, by 40 days after the war, dropped by 15 to more than 40 centigrade degrees over much of the globe, including a vast region extending from Chad to Novosibirsk, from the Caspian Sea to Sri Lanka, embracing India, Pakistan and western China, and having its most severe effects in Afghanistan, Iran and Saudi Arabia. V. V. Alexandrov and G. L. Stenchikov, preprint, Computing Center, U.S.S.R. Academy of Sciences, Moscow, 1983.

But even if it were possible to build perfectly effective shelters for the entire populations of the United States and the Soviet Union, this would in no way address the danger to which the rest of the world would be put. Shelters for the combatant nations under circumstances in which only their citizens are threatened are one thing. Shelters for the combatant nations when gravely threatened noncombatant nations have only rudimentary or nonexistent shelters are a very different matter.

7. *Ballistic-Missile Defense Systems.* It might be argued that the prospect of a climatic catastrophe strengthens whatever arguments there may be for ground-based or space-based ballistic missile defense (BMD) systems, as proposed by President Reagan in his March 23, 1983 "Star Wars" speech. There are grave technical, cost and policy difficulties with such proposals.[24] Even advocates do not envision it being fully operational in less than two or three decades.

Optimistic informed estimates of porosity or "penetrance" (the fraction of attacking missiles successfully detonating at their targets despite the BMD) are no lower than 5 to 30 percent. The present world arsenal of strategic warheads is so much greater than the threshold for climatic catastrophe that, even if 5 to 30 percent of attacking missiles get through in something like a full exchange, the catastrophe could be triggered. And most competent estimates put the porosity—at least for the foreseeable future—at 50 percent to 99 percent. Further, one likely response to an adversary's anticipated deployment of BMD systems would be a proportionate increase in the stockpiles of offensive warheads in compensation.

There are three phases in the trajectories of incoming missiles when they might be attacked: boost phase, midcourse phase, and terminal phase. Boost-phase and midcourse interception would, at best, require an untried technology deployed at scales never before attempted. Only terminal-phase BMDs exist at the present time (antiballistic missiles or ABMs), and even they, ineffective as they are, may require ruinous capital investments before they can provide meaningful levels of defense. Developments in terminal-phase maneuverability of attacking warheads are likely to raise the price tag of an effective BMD sharply again. Even in the best of circumstances, offense will be more effective and less costly than defense.

Finally, terminal-phase interception, generally effective only for hard-target defense, is characteristically designed to occur at very low altitudes. There would be an advantage to the offense if it fused the incoming missiles so they would explode if attacked ("sympathetic detonation"). In some schemes, the BMD itself involves nuclear warheads exploded near the ground. A fair fraction of hard targets, especially in Europe and the Soviet Union, are within a few tens of kilometers of cities or forests. Thus, the most readily deployable BMD suffers the disability, when it works at all, of generating fires contributory to a climatic catastrophe, quite apart from its porosity.

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[24] Richard Garwin, testimony before the Subcommittee on International Security and Scientific Affairs of the House Committee on Foreign Affairs, U.S. Congress, November 10. 1983; Hans Bethe, manuscript in preparation.

8. *Other Possibilities.* There are a number of other conceivable responses to the climatic catastrophe, some even more desperate than those discussed above. For example, a nation might relocate its silos and mobile launchers (the latter inviting barrage attack) to cities and forests to guarantee that a barely adequate counterforce first strike by its adversary would trigger a global climatic catastrophe with high confidence. Or nations with small nuclear arsenals or marginal strategic capability might contemplate amassing a threshold arsenal of some 500 to 2,000 deliverable warheads in order to be taken seriously in "great power" politics.

But these and similar contrivances increase the probability of nuclear war or the dangers attendant to nuclear war sufficiently that they are likely to be rejected by the nation contemplating such moves or, failing that, by other nations. Major relocations of strategic weapons systems or the deployment of new strategic arsenals are readily detectable by national technical means.

V

None of the foregoing possible strategic and policy responses to the prospect of a nuclear war-triggered climatic catastrophe seem adequate even for the security of the nuclear powers, much less for the rest of the world. The prospect reinforces, in the short run, the standard arguments for strategic confidence-building, especially between the United States and the Soviet Union; for tempering puerile rhetoric; for resisting the temptation to demonize the adversary; for reducing the likelihood of strategic confrontations arising from accident or miscalculation; for stabilizing old and new weapons systems—for example, by de-MIRVing missiles; for abandoning nuclear-war-fighting strategies and mistrusting the possibility of "containment" of a tactical or limited nuclear war; for considering safe unilateral steps, such as the retiring of some old weapons systems with very high-yield warheads; for improving communications at all levels, especially among general staffs and between heads of governments; and for public declarations of relevant policy changes. The United States might also contemplate ratification of SALT II and of the 1948 U.N. Convention on the Prevention and Punishment of the Crime of Genocide (ratified by 92 nations, including the Soviet Union).

Both nations might consider abandoning apocalyptic threats and doctrines. To the extent that these are not credible, they undermine deterrence; to the extent that they are credible, they set in motion events that tend toward apocalyptic conclusions.

In the long run, the prospect of climatic catastrophe raises real questions about what is meant by national and international security. To me, it seems clear that the species is in grave danger at least until the world arsenals are reduced below the threshold for climatic catastrophe; the nations and the global civilization would remain vulnerable even at lower inventories. It may even be that, now, the only credible arsenal is below threshold. George Kennan's celebrated proposal[25] to reduce the world arsenals initially to 50 percent of their current numbers is recognized as hard enough to implement. But it would be only the first step toward what is now clearly and urgently needed—a more than 90-percent reduction (Kennan proposed an ultimate reduction of more than 84 percent—adequate for strategic deterrence, if that is considered essential, but unlikely to trigger the nuclear winter. Still further reductions could then be contemplated.

The detonation of weapons stockpiles near or above threshold would be, we can now recognize, in contravention of the 1977 Geneva Convention on The Hostile Use of Environmental Modification Techniques, signed by 48 nations and duly ratified by the Soviet Union and the United States.[26] And Article 6 of the 1968 Nuclear Non-Proliferation Treaty requires the United States and the Soviet Union, among other signatory states, "to pursue negotiations in good faith on effective measures relating to cessation of the nuclear arms race at an early date and to nuclear disarmament. . . ." I do not imagine that these treaties can, by themselves, play a determining role in producing major reductions in the world strategic arsenals, but they establish some sense of international

[25] George F. Kennan, "The Only Way Out of the Nuclear Nightmare," *Manchester Guardian Weekly*, May 31, 1981. This is Kennan's acceptance speech for the Albert Einstein Peace Prize on May 19, 1981, in Washington, D.C.

[26] Article 1, paragraph 1, states: "Each State Party to this Convention undertakes not to engage in military or any other hostile use of environmental modification techniques having widespread, long-lasting or severe effects as the means of destruction, damage, or injury to another State Party." Paragraph 2 goes on: "Each State Party to this Convention undertakes not to assist, encourage or induce any State, group of States or international organization to engage in activities contrary to the provisions of paragraph 1 . . ."

obligation and can at least expedite urgent bilateral and multilateral consultations.

VI

We have, by slow and imperceptible steps, been constructing a Doomsday Machine. Until recently—and then, only by accident—no one even noticed. And we have distributed its triggers all over the Northern Hemisphere. Every American and Soviet leader since 1945 has made critical decisions regarding nuclear war in total ignorance of the climatic catastrophe. Perhaps this knowledge would have moderated the subsequent course of world events and, especially, the nuclear arms race. Today, at least, we have no excuse for failing to factor the catastrophe into long-term decisions on strategic policy.

Since it is the soot produced by urban fires that is the most sensitive trigger of the climatic catastrophe, and since such fires can be ignited even by low-yield strategic weapons, it appears that the most critical ready index of the world nuclear arsenals, in terms of climatic change, may be the total *number* of strategic warheads. (There is some dependence on yield, to be sure, and future very low-yield, high-accuracy burrowing warheads could destroy strategic targets without triggering the nuclear winter, as discussed above.) For other purposes there are other indices—numbers of submarine-launched warheads, throw-weight (net payload deliverable to target), total megatonnage, etc. From different choices of such indices, different conclusions about strategic parity can be drawn. In the total number of strategic warheads, however, the United States is "ahead" of the Soviet Union and always has been.

Very roughly, the level of the world strategic arsenals necessary to induce the climatic catastrophe seems to be somewhere around 500 to 2,000 warheads—an estimate that may be somewhat high for airbursts over cities, and somewhat low for high-yield groundbursts. The intrinsic uncertainty in this number is itself of strategic importance, and prudent policy would assume a value below the low end of the plausible range.

National or global inventories above this rough threshold move the world arsenals into a region that might be called the "Doomsday Zone." If the world arsenals were well below this rough threshold, no concatenation of computer malfunction, carelessness, unauthorized acts, communications failure, miscalculation and madness in high office could unleash the nuclear winter. When global arsenals are above the threshold, such a catastrophe is at least possible. The further above threshold we are, the more likely it is that a major exchange would trigger the climatic catastrophe.

Traditional belief and childhood experience teach that more weapons buy more security. But since the advent of nuclear weapons and the acquisition of a capacity for "overkill," the possibility has arisen that, past a certain point, more nuclear weapons do not increase national security. I wish here to suggest that, beyond the climatic threshold, an increase in the number of strategic weapons leads to a pronounced *decline* in national (and global) security. National security is not a zero-sum game. Strategic insecurity of one adversary almost always means strategic insecurity for the other. Conventional pre-1945 wisdom, no matter how deeply felt, is not an adequate guide in an age of apocalyptic weapons.

If we are content with world inventories above the threshold, we are saying that it is safe to trust the fate of our global civilization and perhaps our species to all leaders, civilian and military, of all present and future major nuclear powers; and to the command and control efficiency and technical reliability in those nations now and in the indefinite future. For myself, I would far rather have a world in which the climatic catastrophe cannot happen, independent of the vicissitudes of leaders, institutions and machines. This seems to me elementary planetary hygiene, as well as elementary patriotism.

Something like a thousand warheads (or a few hundred megatons) is of the same order as the arsenals that were publicly announced in the 1950s and 1960s as an unmistakable strategic deterrent, and as sufficient to destroy either the United States or the Soviet Union "irrecoverably." Considerably smaller arsenals would, with present improvements in accuracy and reliability, probably suffice. Thus it is possible to contemplate a world in which the global strategic arsenals are below threshold, where mutual deterrence is in effect to discourage the use of those surviving warheads, and where, in the unhappy event that some warheads are detonated, there is little likelihood of the climatic catastrophe.[27]

To achieve so dramatic a decline in the global arsenals will require not only heroic measures by both the United States and the Soviet Union—it will also require consistent action by Britain, France and China, especially when the U.S. and Soviet arsenals are significantly reduced. Currently proposed increments in the arsenals at least of France would bring that nation's warhead inventory near or above threshold. I have already remarked on the strategic instability, in the context of the climatic catastrophe only, of the warhead inventories of these nations. But if major cuts in the U.S. and Soviet arsenals were under way, it is not too much to hope that the other major powers would, after negotiations, follow suit. These considerations also underscore the danger of nuclear weapons proliferation to other nations, especially when the major inventories are in steep decline.

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[27] Since higher-yield tactical warheads can also be used to burn cities, and might do so inadvertently, especially in Europe, provision for their elimination should also eventually be made. But initial attention should be directed to strategic warheads and their delivery systems.

Figure 2, on the following page, illustrates the growth of the American and Soviet strategic inventories from 1945 to the present.[28] To minimize confusion in the Figure, the British, French and Chinese arsenals are not shown; they are, however, as just mentioned, significant on the new scale of climatically dangerous arsenals. We see from the Figure that the United States passed the Doomsday Threshold around 1953, and the Soviet Union not until about 1966. The largest disparity in the arsenals was in 1961 (a difference of some 6,000 warheads). At the present time the disparity is less than it has been in any year since 1955. A published extrapolation of the present strategic arsenals into 1985 is shown as dashed, nearly vertical lines, accommodating new U.S. (Pershing II, cruise, MX and Trident) and Soviet (SS-21, -22, -23) strategic systems. If these extrapolations are valid, the United States and the Soviet Union would have almost identical numbers of inventories by the late 1980s.

The uppermost (dash-dot) curve in Figure 2 shows the total U.S. and Soviet arsenals (essentially the world arsenals) climbing upward since about 1970 with a very steep slope, the slope steepening still more if the projection is valid. Such exponential or near-exponential runaways are expected in arms races where each side's rate of growth is proportional to its perception of the adversary's weapons inventory; but it is likewise clear that such rapid growth cannot

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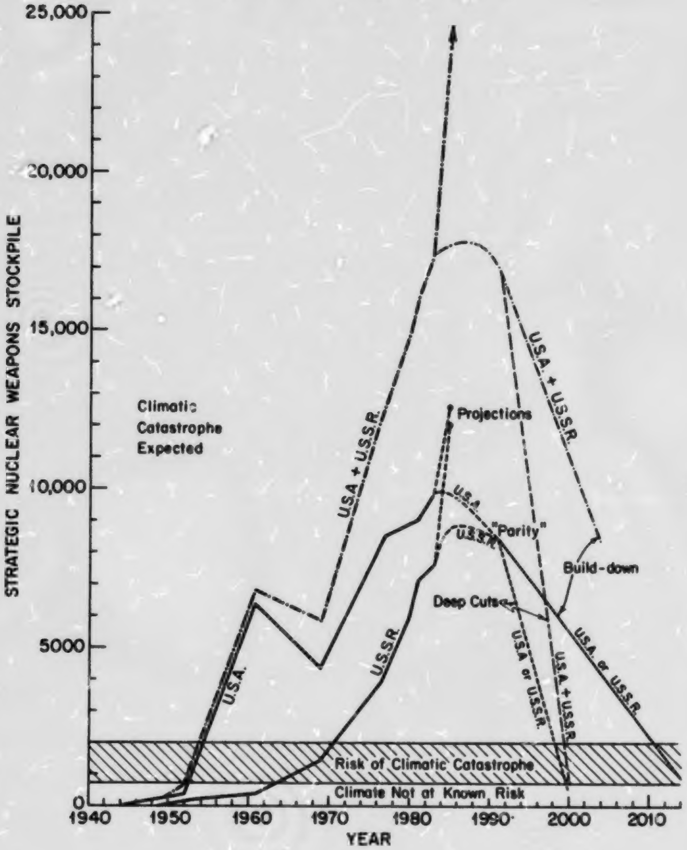
[28] The total warheads calculated in Figure 2 include strategic and theater weapons, but not tactical weapons. Not all published sources are in perfect agreement on these numbers. The principal sources used here are the *Report of the Secretary of Defense [Harold Brown] to the Congress on the FY 1982 Budget, FY 1983 Authorization Request* and *FY 1986 Defense Programs*, Washington: Department of Defense, 1981; and *National Defense Budget Estimates, FY 1983*, Office of the Assistant Secretary of Defense, Comptroller, March 1982.

Beyond 1983, projected increases in arsenals are shown for U.S. and Soviet arsenals as nearly vertical dashed lines, with the sum of these arsenals as the line at the top of the Figure terminating in an arrowhead. The data are from Frank Barnaby in the special issue of *Ambio* cited in footnote 5, pp. 76–83. See also *Counterforce Issues for the U.S Strategic Nuclear Forces*, Congressional Budget Office, January 1978.

Figure 2 shows three regions: an upper region in which the nuclear winter could almost certainly be triggered; a lower region at which it could not be triggered; and a transition zone, shown shaded. The boundaries of this transition zone are more uncertain than shown, and depend among other things on targeting strategy. But the threshold probably lies between several hundred and a few thousand contempory strategic weapons.

FIGURE 2
PAST AND FUTURE NUCLEAR STOCKPILES



continue indefinitely. In all natural and human systems, such steep growth rates are eventually stopped, often catastrophically.

It is widely agreed—although different people have different justifications for this conclusion—that world arsenals must be reduced significantly. There is also general agreement, with a few demurrers, that at least the early and middle stages of a significant decline can be verified by national technical means and other procedures. The first stage of major arms reduction will have to overcome a new source of reluctance, when almost all silos could be reliably destroyed in a sub-threshold first strike. To overcome this reluctance, both sides will have prudently maintained an invulnerable retaliatory force, which itself would later move to sub-threshold levels. (It would even be advantageous to each nation to provide certain assistance in the development of such a force by the other.)

As arsenals are reduced still further, the fine tuning of the continuing decline may have to be worked out very carefully and with additional safeguards to guarantee continuing rough strategic parity. As threshold inventories are approached, some verifiable upper limits on yields as well as numbers would have to be worked out, to minimize the burning of cities if a nuclear conflict erupted. On the other hand, the deceleration of the arms race would have an inertia of its own, as the acceleration does; and successful first steps would create a climate conducive to subsequent steps.

There are three proposals now prominently discussed in the United States: Nuclear Freeze, Build-Down, and Deep Cuts. Their possible effects are diagrammed in Figure 2. They are by no means mutually exclusive, nor do they exhaust the possible approaches. A negotiated Freeze would at least prevent the continuing upward escalation in stockpiles, would forestall the deployment of more destabilizing systems, and would probably be accompanied by agreement on immediate annual phased reductions (the curved lines in the middle to late 1980s in Figure 2). To reduce the perceived temptation for a first strike, de-MIRVing of missiles during arms reduction may be essential.

The most commonly cited method of following the Freeze with reductions is incorporated in the Kennedy-Hatfield Freeze Resolution: percentage reductions. Under this approach, the two sides would agree on a percentage—often quoted as being between five percent and ten percent—and would agree to decrease deployed warheads by that percentage annually. The percentage reduction method was proposed to the Soviet Union by the United States at the Vienna Summit in June 1979 and was to be applied to the limits and sub-limits of the SALT II accords until these reached a reduction of 50 percent.

The Build-Down proposal is one in which modernization is permitted, but each side must pay a price in additional reductions of warheads for each warhead mounted on a modernized missile. In many current versions of the proposal, it would also require both sides to decrease their total warhead inventories by about five percent a year (again, the percentage annual reduction approach), to ensure that at least some reductions would take place even if modernization did not. The rate of decline for Build-Down illustrated in Figure 2 is essentially that of Representative Albert Gore (D.-Tenn.), in which rough parity at 8,500 warheads each is adopted as a goal for 1991–92, and the levels are reduced to 6,500 warheads each by 1997.[29]

There is concern that the "modernization" of strategic systems that Build-Down encourages might open the door to still more destabilizing weapons. It is also by no means clear that all proponents of Build-Down envision further reductions below the interim goal of about 5,000 warheads each for the United States and Soviet Union. If this rate of Build-Down continued indefinitely, the two nations would not cross back below threshold until about the year 2020. As dramatic a change from the present circumstances as this represents, in light of the present global crisis, it is, I think, too leisurely a pace.

Deep Cuts, originally advocated by George Kennan and Noel Gayler[30] as an initial halving of the global arsenals in some relatively short period of time, proposes the turning in of the fission triggers of thermonuclear weapons, deployed or undeployed, to a binational or multinational authority, with the triggers subsequently gainfully consumed in nuclear power plants (the ultimate in beating swords into plowshares). A highly schematic curve for something like Deep Cuts is also shown in Figure 2, starting from Gore's assumption of parity by 1991–92. Halving of the present global arsenals would then occur around 1995, and the global arsenals would return to below the Doomsday Threshold by the year 2000.

The actual shape of these declining curves would very likely have kinks and wiggles in them to accommodate the details of a bilaterally—and eventually multilaterally—agreed-upon plan to reduce the arsenals without compromising the security of any of the nuclear powers. The Deep Cuts curve shown has a rate of decline only about as steep as the rate of rise beginning in 1970. Much steeper declines may be feasible and should be considered.

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[29] *Congressional Record*, August 4, 1983, Vol. 129, No. 114.

[30] George F. Kennan, *loc. cit.* footnote 24; Noel Gayler, "How to Break the Momentum of the Nuclear Arms Race," *The New York Times Magazine*, April 25, 1982.

No one contends it will be easy to reverse the nuclear arms race. It is required at least for the same reasons that were used to justify the arms race in the first place—the national security of the United States and the Soviet Union. It is necessarily an enterprise of great magnitude. John Stuart Mill said: "Against a great evil, a small remedy does not produce a small result. It produces no result at all." But if the same technical ingenuity, dedication and resources were devoted to the downward slopes in Figure 2 as to the upward slopes, there is no reason to doubt that it could be negotiated safely.

In the deployment of more stabilizing weapons systems, in the possible development—especially in later stages of arms reductions—of novel means of treaty verification, and (perhaps) in the augmentation of conventional armaments, it will, of course, be expensive.

But, given the stakes, a prudent nuclear power should be willing to spend more every year to defuse the arms race and prevent nuclear war than it does on all military preparedness. For comparison, in the United States the annual budget of the Department of Defense is about 10,000 times that of the Arms Control and Disarmament Agency, quite apart from any questions about the dedication and effectiveness of the ACDA. The equivalent disparity is even greater in many other nations. I believe that the technical side of guaranteeing a major multilateral and strategically secure global arms reduction can be devised and deployed for considerably less—perhaps even a factor of 100 less—than the planet's direct military expenditures of $540 billion per year.[31]

Such figures give some feeling for the chasm that separates a prudent policy in face of our present knowledge of nuclear war from the actual present policies of the nuclear powers. Likewise, nations far removed from the conflict, even nations with little or no investment in the quarrels among the nuclear powers, stand to be destroyed in a nuclear war, rather than benefiting from the mutual annihilation of the superpowers.. They too, one might think, would be wise to devote considerable resources to help ensure that nuclear war does not break out.

VII

In summary, cold, dark, radioactivity, pyrotoxins and ultraviolet light following a nuclear war—including some scenarios involving only a small fraction of the world strategic arsenals—would imperil every survivor on the planet. There is a real danger of the extinction of humanity. A threshold exists at which the climatic catastrophe could be triggered, very roughly around 500–2,000 strategic warheads. A major first strike may be an act of national suicide, even if no retaliation occurs. Given the magnitude of the potential loss, no policy declarations and no mechanical safeguards can adequately guarantee the safety of the human species. No national rivalry or ideological confrontation justifies putting the species at risk. Accordingly, there is a critical need for safe and verifiable reductions of the world strategic inventories to below threshold. At such levels, still adequate for deterrence, at least the worst could not happen should a nuclear war break out.

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[31] Ruth Leger Sivard, *World Military and Social Expenditures*, Leesburg (Va.): World Priorities, 1983.

National security policies that seem prudent or even successful during a term of office or a tour of duty may work to endanger national—and global—security over longer periods of time. In many respects it is just such short-term thinking that is responsible for the present world crisis. The looming prospect of the climatic catastrophe makes short-term thinking even more dangerous. The past has been the enemy of the present, and the present the enemy of the future.

The problem cries out for an ecumenical perspective that rises above cant, doctrine and mutual recrimination, however apparently justified, and that at least partly transcends parochial fealties in time and space. What is urgently required is a coherent, mutually agreed upon, long-term policy for dramatic reductions in nuclear armaments, and a deep commitment, embracing decades, to carry it out.

Our talent, while imperfect, to foresee the future consequences of our present actions and to change our course appropriately is a hallmark of the human species, and one of the chief reasons for our success over the past million years. Our future depends entirely on how quickly and how broadly we can refine this talent. We should plan for and cherish our fragile world as we do our children and our grandchildren: there will be no other place for them to live. It is nowhere ordained that we must remain in bondage to nuclear weapons.

Senator **Proxmire**. Thank you. As I say, Mr. Sagan, that was a marvelous presentation.

Our next witness is former Assistant Secretary of Defense, Russell Murray. He is presently principal at the Systems Research & Applications Corp. Mr. Murray, we would like to have you go right ahead.

STATEMENT OF RUSSELL MURRAY II, SYSTEMS RESEARCH & APPLICATIONS CORP.

Mr. **Murray**. Senator Proxmire, members of this distinguished subcommittee, your invitation to appear before you does me a great honor. In view of the subject matter, I accept it in all humility. My place at this witness table should be filled by a Socrates. The issue—arguably the most important in history—is the future of mankind. I am sorry I cannot bring you the wisdom of the ages, for this subject deserves no less.

The possibility suggested by Mr. Sagan and his colleagues that nuclear winter might follow a thermonuclear war is awesome beyond my powers of articulation. To what degree his hypothesis is valid I leave to others far better qualified in the physical sciences than I. About all I can contribute is that Mr. Sagan's range of illustrative scenarios seems reasonable to me.

The key question is what effect the possibility of nuclear winter should have on our policies regarding thermonuclear war. My answer may sound surprising, particularly in view of Mr. Sagan's presentation, but it is that nuclear winter should have no effect on the policies that we should adopt. I believe that our future policies should be the same whether nuclear winter is a certainty or a mirage.

If I may draw an analogy, a prudent sailor at sea in a small boat, hearing a forecast of 150-mph winds and 50-foot seas, will take certain actions to save himself. Suppose then that the Weather Bureau raises the forecast to 200-mph winds and 100-foot seas. Should his actions be any different?

The point is not whether nuclear winter would make the effects of thermonuclear war even worse—of course it would. The point is whether its additional effects would induce us to take actions that we would not take if we faced only thermonuclear war and not nuclear winter. I think the answer must be no. Thermonuclear war alone should be enough to dictate our policies.

No doubt the prediction of nuclear winter involves many uncertainties, primarily in the physical sciences. But the physicists at least have some data from weapons tests, from volcanic eruptions, from ice-age climatology, and so on, from which to make their grim extrapolations. The basis that the social scientists have for estimating the effects of thermonuclear war on the fabric of modern society—even without the horror of nuclear winter—seems much weaker and the uncertainties accordingly greater.

It is true that World War II showed us the effects of firestorms on Hamburg and Dresden and the effects of small nuclear weapons on Hiroshima and Nagasaki, but those were single cities, not whole nations. It also showed us the effects of deaths in the tens of millions, but over a period of years, not hours. We have never seen anything remotely like thermonuclear war. We have never seen anything like cataclysmic effects that are: One, virtually instantaneous—occurring in a matter of hours, rather than spread out over months or years, allowing time for accommodation; two, spread over vast geographical areas simultaneously—not just a few cities at a time, allowing help to come from surrounding areas; and three, imposed on a society as complex, interdependent, and—indeed—delicate as ours has become today.

Some seem to believe that the survivors of thermonuclear war could regress to the more primitive existence of colonial days, and rebuild the United States once more. Perhaps given enough time and training, today's supermarket shopper could learn the arts of primitive agriculture—an agriculture with no tractors, no fertilizers, or pesticides, no mail-order seeds, no irrigation pumps, no refrigeration, no 18-wheeler semitrailers for distribution. But could he learn that before any surviving preway food supplies ran out? Could he find enough uncontaminated arable land within walking distance to feed himself, even if he knew how to farm it? Could he protect his crops—not to mention his life—from other desperate survivors? Where would he get his water? Would he know how or where to dig a well, and whether the water was safe? What about sanitation? Would he and his fellow survivors be able to dispose of the tens or hundreds of millions of human and animal corpses, or would epidemics wipe out the rest? Faced with such a bleak and melancholy prospect, could the survivors keep their sanity? Would they choose to struggle on or turn to suicide?

Nobody can be certain of the answers to those and similar questions; the extrapolation beyond what we know from experience is just too great. But we must think of the possibilities, even if we can't quantify them. Perhaps some form of civilization, even if terribly primitive, might survive a major thermonuclear exchange without nuclear winter. But perhaps not.

That must be a matter of judgment, but to me the judgment is clear. I have little enough confidence that even a primitive society—primitive agriculture, primitive shelter, primitive law and order, and all the requisites for survival that we now so easily take for granted—would be possible in the wake of a major thermonuclear war, even without nuclear winter. But I have even less confidence in the possibility of transitioning to such a primitive society in a matter of weeks or months. The effects would be too sudden, too widespread, and too disruptive of the intricate fabric of a society it has taken centuries to build and on which we have become almost totally dependent.

The risks are so great and the uncertainties so large that our policies must not be based on the expectation of surviving—much less winning—a major thermonuclear war. I make that assertion even though I cannot prove that survival is impossible. And I hold to it whether nuclear winter is real or imagined. Nuclear winter only reinforces the conclusion. Our policies should be the same in either case.

What should those policies be? I can think of three general objectives: To diminish the likelihood of thermonuclear war breaking out; to limit the damage if it should; and to reduce the expense of nucler forces. I'd like to discuss those in reverse order.

With regard to expense, though we spend only 10 percent or 20 percent of the defense budget on strategic nuclear forces, that's still a lot of money. There are two ways to cut those expenses: Reduce the forces; and make them more efficient.

Reducing our forces unilaterally can be dangerous and destabilizing. Reducing them through bilateral or multilateral arms control agreements is a much better choice, though progress in that area has been slow even under the best of conditions. Perhaps Mr. Sagan's findings will accelerate the process.

The other way of economizing—making the strategic nuclear forces more efficient—holds more immediate promise. The B-1 bomber is an egregious example of inefficiency. It's not the B-1 would be useless; it's just that it's not worth its immense cost: roughly a quarter of a billion dollars a copy. Though it can also carry cruise missiles, the B-1's basic design is predicated on trying to penetrate the Soviets' extensive air defenses. A far better alternative would be an aircraft designed only to launch cruise missiles from outside the defense perimeter. Free of the B-1's demanding performance requirements, complex electronic equipment, and reliance on tankers, such an aircraft would be less expensive, and its tiny cruise missiles would be far more difficult targets for Soviet air defenses than the huge B-1.

Savings are possible in the near term from such efficiencies, and in the longer term from negotiated force reductions. How should those savings be appied? One could argue that they should be reallocated to the nondefense sector of the Government, or to the private sector. But if our principal concern is avoiding thermonuclear war and nuclear winter, I suggest that such savings should be applied to the strengthening of our conventional forces.

To the degree that our conventional forces are seen as weak, the chances of a conventional war increase. And to the degree that they actually are weak, the chances increase that in some future conventional war we might face the choice between escalation and capitulation. Thus, strong conventional forces are important in avoiding nuclear war.

Accordingly, it should be our policy to reduce the cost of strategic nuclear forces through efficiencies and balanced cuts, to the degree that this can be done safely. The savings should be applied to strengthening our conventional forces. However, such economies must never be accorded a higher priority than the two other objectives: Reducing the likelihood of war breaking out; and limiting the damage if it does.

With regard to damage limiting, we and the Soviets now have roughly 50,000 nuclear weapons. An agreement to cut those stockpiles in half would be an unprecedented triumph of arms control. If it could be achieved at all, experience tells us that it would probably take years of negotiation. But even if we were able to achieve that, and then repeat it, and even repeat it again—cutting the stockpiles by a factor of 8—there would still be some 6,000 weapons left. Mr. Sagan's rough threshold for nuclear winter is only a fraction of that figure—500 to 2,000 weapons. To get below that threshold, we would have to negotiate at least two more of those unprecedented 50 percent cuts.

In addition, achieving such low limits implies formidable problems in verification. When both sides have tens of thousands of weapons, another thousand on either side is not liable to make much difference. But if legal stockpiles are limited to a few hundred, another thousand, carefully hidden, could be overwhelming. And the potential for proliferation among third parties further clouds the prospects for tight limits on superpower stockpiles.

Nonetheless, to limit the damage should nuclear war break out, and particularly to lessen the probability—if Mr. Sagan is right—of the ultimate catastrophe of nuclear winter, our policy should also be to work for cuts in the number and yield of nuclear weapons on both sides. But recognizing how far we have to go, how long it's liable to take, and the awful threat facing us right now, this policy must never be accorded a higher priority than our remaining objective: Reducing the likelihood of war breaking out in the first place. If we're going to cut the size of those stockpiles, we've got to stay alive to do it.

As to how we can reduce the likelihood of war, a traditional criterion for our strategic nuclear forces is that they must be strong enough to convince the Soviet leadership that it could not profit from starting—or threatening to start—a thermonuclear war. That criterion covers the case of a confident and supremely aggressive Soviet leadership, set on achieving its goals through the ultimate form of war.

But that criterion is not enough; we must also cover the case of a deeply worried Soviet leadership, convinced in the depth of some deadly crisis that we may be about to attack them. It is a leadership that is persuaded that if they strike first, the devastation that they will suffer from our retaliation—terrible though it would be—will still be less than the devastation they will suffer if they wait for us to strike them first.

This is not a Soviet leadership trying to profit through a thermonuclear war that they want to start, but one trying only to minimize their potential losses in a war they feel forced to start. It is a Soviet leadership contemplating a preemptive thermonuclear attack on us as the lesser of two evils.

This more demanding criterion emphasizes crisis stability. It requires not just that we have forces that could ride out a Soviet preemptive strike, but also that we do not have forces that are both capable of great damage to the Soviet Union and vulnerable to a preventive, preemptive Soviet attack. We must not give the Soviets any hope that, by going first and destroying some vital part of our strategic nuclear forces, they could at least escape some of the destruction from a U.S. attack.

Unfortunately, that is not our policy today. In my opinion, by building the silo-based MX, we are increasing the likelihood of nuclear war. The planned 100 MX's alone should be able to destroy roughly three-quarters of the Soviets' 6,000-odd ICBM warheads if we fire first. But only 20 Soviet SS-18's could virtually wipe out our entire MX force in its vulnerable silos if they fire first. That is a prescription for instability, giving the Soviets a clear incentive to fire first in time of deep crisis.

The MX should be recognized for what it is. In silos and unable to ride out a Soviet attack, it would be useful to us only if we intend to count on the highly unreliable and immensely dangerous policy of launch-on-warning, or if we intend to initiate thermonuclear war. The decision to build a weapon that would be as devastating in a first strike as it would be useless in retaliation marks a fundamental and ominous change in national security policy.

We must stop this reckless irresponsibility. I am not some dovish unilateral disarmer. I believe that weakness is more liable to encourage war than peace. But we can build strong forces—as strong as we want to—without the obsolete, vulnerable, silo-based MX. Instead, we can build more cruise missiles and new aircraft to carry them. We can build more sea-based ballistic missiles. We may even be able to build mobile ICBM's.

But whatever we do, our top priority must be to lessen the chance of thermonuclear war breaking out in the first place. That requires that we have strategic nuclear forces that are strong, stabilizing, backed by credible targeting policies, and not temptingly vulnerable. It also requires that we have strong non-nuclear-forces to diminish the likelihood of becoming involved in a conventional war and, if that happens, to diminish the likelihood that we might be forced to choose between capitulation or resort to nuclear weapons.

Lessening the chance that nuclear war might break out is so important that we should be willing to forego the other two objectives if necessary to achieve it. If further financial sacrifices are necessary for adequate strength and stability, we should make them. And if increases rather than cuts in our stockpile are necesssary for adequate strength and stability, we should make them. That might postpone the day when we can finally get the stockpiles below Mr. Sagan's threshold for nucler winter, but if the world blows up in our face before we get there, we won't have a second chance.

In summary, our first priority should be to lessen the likelihood of thermonuclear war breaking out so that we can have a chance of attending to our second priority: reducing nuclear stockpiles. The likely consequences of thermonuclear war alone are deadly enough to mandate those policies. The possibility of nuclear winter as well only reinforces the need for them.

Senator **Proxmire**. Thank you very, very much, Mr. Murray, for a very clear and concise statement and there's no question where you stand on the policies we should follow because of nuclear winter: we shouldn't change at all because of nuclear winter.

Admiral Gayler.

STATEMENT OF ADM. NOEL GAYLER, USN (RETIRED), AMERICAN COMMISSION ON EAST-WEST ACCORD

Admiral **Gayler**. Thank you, Senator. I don't think I will take the time to rehash the incredible damage done by nuclear weapons to civilization. All houses, all buildings destroyed, communications disrupted, hundreds of millions of people dying, some immediately, some of them after protracted agony. All of these are clearly the consequence of any major nuclear exchange.

The question arises whether cities will be struck. In my judgment, based in part on my experience as a targeteer, almost certainly. Most of the deterrent targets, so-called, are imbedded in cities. Whatever the declarative policy of either country, the weapons that go after leadership, weapons that go after control, after military capability, industrial capability, or economic recovery will hit cities. By and large, that's where these capabilities are. You can't attack government without attacking Washington, military leadership without places like Omaha and Norfolk, Honolulu, and Brussels. You can't attack industry without Los Angeles and New York and Houston and Chicago and San Francisco and Seattle and dozens and dozens of other cities.

The one important exception is the missile silos in the Siberian wastes of Russia and in the great plains of the far West here But an attack against silos alone would make no sense at all. Even if you caught a sleeping enemy and destroyed all of his silo weapons before he could fire them out, the retaliation by his other weapons systems—his submarines, bombers, and cruise missiles—would be devastating. There would be no sense to such a silo-only attack.

So we have to face up to it. No matter what our rhetoric is, or their rhetoric is, in a general nuclear war cities will be struck and they will burn.

Well, will not at least some of the smaller cities be spared? I don't think it's likely. With the thousands of nuclear warheads on either side, the problem for the targeteers is not to find enough weapons for the targets, but to find enough plausible targets for the weapons. Under this imperative, the smallest cities become "industrial assets."

Now civil defense can protect neither people nor cities. Nor can antimissile defenses—Star Wars—protect us. The notion that we can have magic bullets—laser beams and energy beams in space, layered defenses and terminal defenses, high frontiers and nuclear x ray lasers to protect cities or population—that idea is illusion.

These schemes, each and every one of them, propose combinations of basically improbably technology at unprecedented scale and unplumbed cost. The technical difficulties are forbidding, and the military even more so. The projected costs for these systems are on the same order as the gross national product.

Even more fundamentally, these proposed systems can all be frustrated by countermeasures that are relatively easy to field and fully effective. And even if ballistic missile defense for cities were somehow to be possible, alternative means of delivery would be unaffected.

There is, of course, no prospect that we will spend the gross national product on a futile attempt to build a Star Wars system to protect populations. There is some chance apparently that we will spend uncounted billions to put up a space battle station, never mind how useless and vulnerable it may be. And there seems to be every chance that we will spend a very great deal of money in arbitrarily pushing Star Wars technology, at the cost of more important technologies, both civil and military.

For all these reasons, I believe the scenarios used to develop the meteorological models leading to the forecast of nuclear winter are quite reasonable. They seem to span the possibilities, from the pointless but possible limited attack on silos alone to the severe case where everything possible is targeted.

I am not competent to evaluate the meteorology and planetary analysis, with its remarkable agreement from the Russian scientific side. But if the analysis is correct even to a degree, three consequences stand out:

There will be no bystanders, at least in the Northern Hemisphere. No country, great or small, will be safe, whether it's at war or not. And the aggressor is not safe, even if there is no retaliation.

Since the number of weapons required to trigger the nuclear winter is comparatively low, the idea of nuclear balance becomes meaningless, at least in the physical world.

Correspondingly, cheating on an agreement, sufficient to make a difference would have to be immense. Verification is therefore assured.

Now I want to take very sharp exception with Mr. Murray's suggestion that the existence of nuclear winter need make no difference in our policies. It will have these consequences at least: One, the aims of FEMA toward convincing us that we ought to spend a lot of money on civil defense are misplaced; two, there will be no bystanders whether countries are at war or not; three, there will be automatic retribution against an aggressor; four, there is no Star Wars technology that will protect us; and five, there is no prospect of safety through technical advantage of some kind, or even much larger nuclear programs.

I think these are important consequences of the nuclear winter. With Mr. Murray's general objective to reduce the likelihood, the consequences and expense of nuclear war, I could do no more than agree; but the prospect of nuclear winter reinforces the already totally unacceptable character of nuclear war.

I'd like to quote George Kennan once more, "There is no issue at stake in our political relations with the Soviet Union—no hope, no fear, nothing to which we aspire, nothing we would like to avoid—which could conceivably be worth a nuclear war, which could conceivably justify the resort to nuclear weaponry." This is not a doctrine of "Red or Dead." We need be neither, for our necessary defense in an imperfect world can be assured by economic strength, political strength and usable military strength, observing that nuclear weapons have no rational military use at all.

I don't think many people recognize the peacetime economic costs of nuclear weapons systems. For example, turning to new systems only, we now have in the present program nine weapon systems with strategic capability, under current development. I'll tick them off. That's three types of cruise missiles; two types of bombers; two kinds of intercontinental ballistic missiles; a new submarine-launched ballistic missile; and Pershing II. There are nine.

Together the program costs—and it's extraordinarily difficult to forecast these costs, but it's reasonable to believe that the aggregate program costs will not be less than, and may well exceed greatly $200 billion. We can and should negotiate with the Soviets to drop all such new systems and that will have no risk to our deterrent posture or to theirs. There are much more compelling reasons to get rid of or cut back these dangerous and destabilizing weapons, but the financial reasons are good enough.

There are other ways to scrutinize defense and I agree pretty much with Mr. Murray's analysis of what we should do. Certainly strengthen our conventional forces in ways which make sense is a useful way of reducing the likelihood of nuclear war, at least in the short term. But there are no ways to scrutinize defense that have such clear-cut advantages, so little risk and such obvious improvement to our own security, as eliminating new nuclear weapons development. The immediate savings are large. The potential savings are tremendous. The reduction in the risk of nuclear war is beyond price.

We can have no confidence that nuclear war, however started, will not escalate to general war. We have seen that general war would be a catastrophe beyond imagining. We understand that however we may try, we cannot be secure against nuclear war by our own efforts alone. It must be at least a two-handed game with the Soviets. We need a vision, both large and pragmatic: A general nuclear settlement with the Soviet Union, to be joined at the appropriate time by the other nuclear powers. Nothing less will assure our security.

[The prepared statement of Admiral Gayler follows:]

PREPARED STATEMENT OF ADM. NOEL GAYLER

There can be no real doubt about the consequence of major nuclear war to the countries at war. No one disputes the incredible damage done to cities, government, industry, agriculture, public works and the military by multiple nuclear blasts. Buildings, homes, hospitals, facilities are destroyed. The complex web of transportation and communication is totally disrupted. The life-giving land, the air, and the water alike are poisoned. Livestock are killed, crops destroyed. Human beings in their hundreds of millions die, some instantly, some in protracted agony. Now the new and credible studies you are examining show that a major exchange may end human nearly everywhere through the privations and traumas of a protracted nuclear winter.

Will cities be struck? Almost certainly. The deterrent targets are imbedded in them. Whatever the declarative policy of either country, the weapons that go after leadership, control, military capability, industrial capability, or economic recovery will hit cities. By and large, that's where these capabilities are. You can't attack government without Washington, military leadership without places like Omaha and Norfolk, Honolulu and Brussels, industry without Los Angeles and New York, Chicago and San Francisco, Houston and Seattle, and scores of other cities.

The one important exception is the missile silos in the Siberian wild or the great plains of the West. But surely an attack against missile silos alone makes no sense. To the degree that they are vulnerable, such an attack would only cause the adversary to fire on warning, or even shoot first. Nothing could be more dangerous and destabilizing than such plans. Even if attacks were to be effective against the missile silos of a sleeping enemy retribution by submarines, bombers, and cruise missiles would be unaffected.

We must face up to it. Whatever our rhetoric or theirs, in a general nuclear war cities will be struck, and they will burn.

Will not at least some of the smaller cities be spared? Not likely. With the thousands of nuclear warheads on either side, the problem for the targeteers is not to find enough weapons for the targets, but to find enough plausible targets for the weapons. Under this imperative, the smallest cities become "industrial assets."

Civil defense can protect neither people nor cities. Nor can anti-missile defenses -- STAR WARS protect us. The notion that we can have magic bullets -- laser beams and energy beams in space, layered defenses and terminal defenses, high frontiers and nuclear x-ray lasers to protect cities or populations is illusion.

These schemes, each and every one, propose combinations of basically improbable technology at unprecedented scale and unplumbed cost. The technical difficulties are forbidding, and the military even more so. The projected costs are of the same order as the gross national product.

Even more fundamentally, these proposed systems can all be frustrated by countermeasures that are relatively easy to field and fully effective. And even if ballistic missile defenses for cities were somehow to be possible, alternate means of delivery would be unaffected.

There is of course no prospect that we will spend the gross national product on a futile attempt to build a STAR WARS system to protect populations. There is some chance apparently that we will spend uncounted billions to put up a space battle station, never mind how useless and vulnerable it may be. And there seems to be every chance that we will spend a very great deal of money in arbitrarily pushing STAR WARS technology, at the cost of more important technologies, both civil and military.

For these reasons, I believe the scenarios used to develop the meterological models leading to the forecast of Nuclear Winter are quite reasonable. They seem to span the possibilities, from the pointless but possible limited attack on silos alone to the severe case where everything possible is targeted.

I am not competent to evaluate the meteorology and planetary analysis, with its remarkable agreement from the Russian scientific side. But if the analysis is correct even to a degree, three consequences stand out:

o There will be no bystanders, at least in the Northern Hemisphere. No country, great or small, will be safe, whether at war or not. The aggressor is not safe, even if there is no retaliation.

o Since the number of weapons required to trigger the nuclear winter is comparatively low, the idea of nuclear balance becomes meaningless, at least in the physical world.

o Correspondingly, cheating on agreement, sufficient to make a difference, would have to be immense. Verification is therefore assured.

The policy implications of this analysis are straightforward. The prospect of nuclear winter reinforces the already totally unacceptable character of nuclear war. There is no chance of useful technical advantage, whether in offense or defense. To quote George Kennan, "there is no issue at stake in our political relations with the Soviet Union -- no hope, no fear, nothing to which we aspire, nothing we would like to avoid -- which could conceivably be worth a nuclear war, which could conceivably justify the resort to nuclear weaponry." This is not a doctrine of "Red or Dead." We need be neither, for our necessary defense in an imperfect world can be assured by economic strength, political strength and usable military strength, observing that nuclear weapons have no rational military use at all.

Few people recognize the peace-time economic costs of nuclear weapons. For instance, the nine new strategic weapons systems now in the budget process plus the almost innumerable new tactical nuclear systems will aggregate at least 200 billion dollars in the course of their program development. We can and should negotiate with the Soviets to drop all such new systems without risk to our deterrent posture, or theirs. There are much more compelling reasons to get rid of or cut back these dangerous and destabilizing weapons, but the financial reasons are good enough.

There are, of course, other ways to scrutinize defense. None has such clear-cut advantages, so little risk and such obvious improvement to our security as eliminating new nuclear weapons development. The immediate savings are large. The potential savings are tremendous. The reduction in the risk of nuclear war is beyond price.

We can have no confidence that nuclear war, however started, will not escalate to general war. We have seen that general war would be a catastrophe beyond imagining. We understand that however we may try we cannot be secure against nuclear war by our own efforts alone, it must be at least a two-handed game with the Soviets. We need a vision, both large and pragmatic: a general nuclear settlement with the Soviet Union, to be joined at the appropriate time by the other nuclear powers. Nothing less will assure our security.

Senator **Proxmire**. Thank you very much, Admiral Gayler, for your excellent statement.

Our final witness is Paul Warnke.

STATEMENT OF PAUL C. WARNKE, ATTORNEY, CLIFFORD & WARNKE

Mr. **Warnke**. Senator Proxmire, Senator Sasser, Congressman Mitchell, I am in the unfortunate position of being last in this group and my informed and articulate colleagues have just about covered the field. Logically, I should yield my time, but I assure you I won't do that.

As Senator Proxmire has pointed out and as has been pointed out by the other speakers today, the findings with respect to the nuclear winter phenomena are just a dramatic addition to the already formidable list of reasons why the world can't afford a nuclear war.

A year ago Andrei Sakharov, the distinguished physicist and courageous Soviet dissident, I think prior to the time of the publication of the findings about nuclear winter, said that:

> Nuclear war, with a certain degree of probability, would cause man to be destroyed as a biological species and could even cause the annihilation of life on earth.

That would in all likelihood be true even without the nuclear winter phenomena.

Now I feel, as I understand Mr. Murray feels, that as a consequence, the findings with respect to nuclear winter should not change the policies that should be followed. I did not take him to say that we should continue to follow the same policies that we have been following.

Mr. **Murray**. That's exactly right.

Senator **Proxmire**. You agree with that, Mr. Murray?

Mr. **Murray**. Yes, indeed. I hope I didn't create a misimpression. I am not endorsing the current policies.

Senator **Proxmire**. Very good.

Mr. **Warnke**. For one thing, we have never really made up our minds what our nuclear policy is. We have the same debate today that we've had for years between those who feel that you can fight a nuclear war rationally, that you can fight it, survive it, and win it, and those who maintain that the sole purpose of nuclear weapons is to prevent a nuclear war from taking place.

Now you can see this debate even within the present administration. Certain statements by Secretary of Defense Caspar Weinberger have indicated his view that we have to have the nuclear forces that will enable us to meet conventional attacks and to prevail, to force termination of nuclear wars on terms favorable to the United States and its allies, even after nuclear weapons have been used.

I find his statements in strange contradiction to President Reagan's State of the Union Message of last January where he said, in a plea to the Soviet people, that a nuclear war cannot be won and must not be fought, and he continued that the only value in our two Nations possessing nuclear weapons is to be sure that they will never be used.

Now if that is the policy, then certainly we ought to shape our nuclear forces in reliance upon that statement of the President.

But if the Secretary of Defense is right with regard to the essential purpose of nuclear weapons being to meet conventional aggression, to prevail in a nuclear war, then the President is wrong. But if the recent scientific findings are correct, then the Secretary of Defense is wrong because the initiation of a nuclear war would in fact destroy both the attacker and the attacked.

This is an instance in which I'm happy to stand with the President and with the scientific evidence.

Unfortunately, even the findings with respect to nuclear winter will not put an end to the debate. There will be those who maintain that as a result of this phenomena what we ought to do is to develop more accurate weapons, of smaller yield, so that we can fight a nuclear war "rationally."

As a matter of fact, that is usually the assertion that advocates of this sort of approach make, that we must have the ability to fight a nuclear war rationally. That obviously is a contradiction in terms. But nonetheless, we have to look for this as one possible reaction to the findings with respect to nuclear winter; that rather than putting an end to the debate—between those who advocate a nuclear war fighting posture and those who say that the sole purpose is to prevent the use of nuclear weapons—it will instead generate pressures for more kinds of nuclear weapons that would lower the nuclear threshold and, in my opinion, give us no chance whatsoever of limiting the escalation of nuclear war.

Again to quote Andrei Sakharov, he said in his open letter in Foreign Affairs about a year ago, that "if any country uses a nuclear weapon even on a limited scale * * * the most probable result would be swift escalation leading from a nuclear war initially limited in scale or by region to an all-out nuclear war; that is, to general suicide."

Now in my prepared statement I have tried to sketch out the absurdity of one of the scenarios for limited nuclear war, the idea of a surgical limited attack directed just against our weapons but not against our people. It would involve, strikes against thousands of weapons, colocated in some instances with cities. Rather than it being a surgical strike, it would be a calamity of unexampled dimensions. There is no such thing, in my opinion, as limited nuclear war.

One idea, for example, is that perhaps you would have just some tests of will, that we'd take out Minsk and they'd take out Dubuque, and then manhood would be satisfied and everybody would figure, OK, the nuclear war is over. I don't see that happening. I think that when one side uses a nuclear weapon against the other side, the reaction is going to be immediate, is going to be brutal. It's going to be devastating. You would have to anticipate that the other side had lost its mind and, as a consequence, all you could do is try and hit as hard as you could in the hope that this would put an end to him before he puts an end to you.

So I think the concept that somehow we can change our nuclear forces to permit us to conduct a rational nuclear war is one of the dangerous possibilities that now exists and it has to be avoided. We are, in fact, building more accurate counterforce weapons, rather than reducing the risks and the consequences of nuclear war.

This seems to me, for the reasons that have been given by my colleagues, to be the dangerous development that only arms control can stop. As the weapons on both sides become accurate, there is increasingly a worry, an apprehension, that the other side may think it has the ability to strike first and prevent retaliation. Now that is not the situation at the present time, but if things like the MX are developed and at the same time the Soviet Union develops its SSX-24, which is a roughly comparable weapon—solid fuel, 10 very accurate warheads—if both sides go ahead with sea-launched cruise missiles, the time could come when, given an intense crisis, each side would have to worry about whether the other side was planning to go first and leave the attacked side short of a retaliatory deterrent.

It seems to me that all of the scientific evidence, all of logic, compels that what we do is to structure our nuclear forces so that they are the most survivable and the least threat to the survivability of the forces on the other side.

What that requires is moving away from counterforce weapons, moving toward the least vulnerable systems, and at the same time having selective reductions in the nuclear arsenals that we already have.

Now I think that that's possible. We aren't going to get greater security by more nuclear weapons, as has been convincingly demonstrated by Carl Sagan. More nuclear weapons means only less security and there's only one way to get less nuclear weapons and that's by agreement. We aren't going to be able to get it by building up our forces in the hope that that will cow the Soviet leadership into giving us arms control by default.

The President in a recent press conference has said that he thinks that the Soviet Union knows that we could outmatch them in a nuclear arms race and that he doesn't believe they could increase their military budget in any place. I know of no informed observer of the Soviet Union, no student of its leadership, who agrees with the President in this respect. They believe that if we build up, the Soviets will build up; and that the only way we're going to get reductions is by agreement.

Can it be achieved? In my opinion, it can, and we already have in place the foundation that would permit us to bring about very substantial and very selective reductions. If we were to combine the talks on intermediate range nuclear forces and those on intercontinental range, that would provide a means by which both sides could get back to the negotiating table without losing face. The Soviet Union then would not have resumed the INF talks but they would be considering the SS-20's—their intermediate range nuclear forces—along with our cruise missiles and Pershings II's, and doing it in the context of the overall strategic balance.

In that context, the British and French forces would be less of an obstacle because they would shrink into relative insignificance. And if we had common ceilings that covered SS-20's along with the Soviets SS-18's and 19's, and similarly with the intermediate range nuclear forces on our side, this would then put heavy pressure against the intermediate range forces because they are the less capable and in many respects the more vulnerable.

Then if what we did is to take those ceilings and subject them to annual reductions, very substantial annual reductions, not just in the overall total because reductions in numbers alone is not enough. As I have said, what we want are the forces that are the most survivable and the least provocative and that would require shrinking the various subceilings that have already been negotiated in SALT I and SALT II, which would mean reductions in the total number of MIRV'd ballistic missiles, reductions in the lower ceiling of the most destabilizing system which is the MIRV'd land-based intercontinental ballistic missile, reductions in the Soviet heavy missiles which are also subject to a present ceiling.

Now that obviously is not the answer. The total answer requires some sort of world accommodation, some kind of international regime, which will make the outbreak of nuclear war impossible. But the best we can do for the present, in my opinion, is to shore up deterrence to make it less and less plausible that either side would ever launch a nuclear war, and so the dependence upon nuclear forces is indeed restricted to what the President said is its only value, which is to prevent the use of those nuclear weapons.

Thank you very much.

[The prepared statement of Mr. Warnke follows:]

PREPARED STATEMENT OF PAUL C. WARNKE

In a more rational world, the recent scientific findings about the consequences of nuclear warfare would intensify the search for prompt and effective measures to reduce the number of nuclear weapons and to increase the stability of the strategic balance. But in a more rational world, the nuclear powers would long since have acted on the often-asserted conclusion that a nuclear war would know no winners and must be prevented.

Even now, however, there are too many who continue to maintain that nuclear weapons can be used rationally and that the accumulation of more sophisticated and accurate counterforce weapons can somehow promote U.S. foreign policy objectives and improve national security. It may be, therefore, that in a nuclear world rationality has no place.

As can be easily demonstrated, I am not a scientist. I have no way, therefore, of evaluating independently the scientific evidence with respect to a "nuclear winter" or the megatonnage that might be required to produce these baleful effects. I am not comforted, however, by the contentions of some that the evidence is inconclusive, that the atmospheric disruption might not be in fact so great as to make the earth inhospitable to human life, or that careful control of yield and targeting would prevent the incineration of cities or industrial facilities. And my discomfort changes to dismay when I read critics of the "nuclear winter" hypothesis who argue that this phenomena should not have been reported until all the uncertainties were significantly reduced. I, for one, am unwilling to wait for conclusive proof that Dr. Sagan and his colleagues are right in their assessment. This is one theory we can't afford to put to the test.

Ironically, the recent scientific analyses of the possible consequences of nuclear warfare will probably inspire yet further debate between those who see nuclear weapons as serving solely a deterrent purpose, and those who believe that a nuclear war can be fought, survived, and won. This debate has gone on ever since nuclear weapons came into the inventories of the United States and the Soviet Union. In recent year statements of the Department of Defense have maintained that our nuclear forces must serve the purpose of enabling the United States to impose termination of a nuclear war "on terms favorable to the United States and our allies." (See e.g., Secretary of Defense Caspar Weinberger's Annual Report to Congress for Fiscal Year 1983, Page I-18). But the President of the United States, in his State of the Union address in January of this year, assured the Soviet people of his conviction that "nuclear war can not be won and must never be fought," and that: "The only value in our two nations possessing nuclear weapons is to be sure that they will never be used." If the Secretary of Defense is right as to the essential purposes of nuclear weapons, then the President is wrong. But if the recent scientific findings are correct, then the Secretary of Defense is wrong because the initiation of a nuclear war would mean suicide for the attacking nation even if its victim were unable to respond with a retaliatory strike. In this instance, I'm happy to stand with the President and the scientific evidence.

The advocates of a nuclear war-fighting capability undoubtedly will contend that this evidence strengthens the case for nuclear weapons of great accuracy and smaller yield that can be used in a limited nuclear war. But what are the realistic limited nuclear war scenarios? Let's consider, for example, the scale of a theoretical preemptive attack. Glib talk about a surgical strike, that might leave the United States with greatly reduced nuclear forces and deterred from retaliating for fear of a further attack against the American population, ignores the number of

Soviet warheads that would have to be launched in order seriously to erode the United States strategic arsenal. We have about 1050 ICBM silos. To have a reasonable chance of destroying a silo, the attacker would have to target it with two warheads - one airburst, one at ground level. This means that 2100 Soviet warheads would have to arrive on target. Any minimally prudent planner must assume that some of these weapons, which have never been fired in anger, wouldn't work or would miscarry. A conservative estimate, therefore, is that some 3000 Soviet strategic warheads would be directed against our Minutemen in their underground silos.

A Soviet preemptive attack would also have to take out our in-port ballistic missile submarines and our Strategic Air Command bases. This so-called surgical strike thus would probably involve commitment of half of the Soviet strategic nuclear arsenal consisting of about 10,000 warheads. No one can be sure what the effects of this number of nuclear explosions might be. The chances are that they would be worse than we can imagine. The debate about whether the United States, thus gravely wounded, would have the heart to retaliate, may well involve a purely academic question. The Soviet Union would have brought about its own likely destruction, perhaps in days or weeks rather than in minutes.

It should be noted that a year ago, in Foreign Affairs, there appeared the eloquent open letter of Andrei Sakharov on "The Danger of Thermonuclear War." Dr. Sakharov, the distinguished Soviet physicist and courageous dissident, gave his opinion that a nuclear war "with a certain degree of probability, would cause man to be destroyed as a biological species and could even cause the annihilation of life on earth." He also stated that "if any country uses a nuclear weapon even on a limited scale... the most probable result would be swift escalation leading from a nuclear war initially limited in scale or by region to an all-out nuclear war, i.e. to general suicide."

Even if the actual consequences might be less cataclysmic than some of these extrapolations, logic should compel giving top priority to end and reverse the nuclear arms race. The notion that greater security can be found in building more American weapons rather than negotiating reductions in Soviet warheads should now be discredited. But the debate continues to rage. Advocates of the MX, of submarine-launched cruise missiles, of greater accuracy and greater counterforce capability argue still that the deployment of these new weapons will lead to Soviet reductions. But this arms race theory of arms control is belied by the entire history of nuclear weapons.

The Soviet boasts of nuclear missile superiority led, in the early 60s, to a missile gap in our favor. And the Soviets responded with their own missile build-up. In the late 60's and early 70's, we deployed MIRVed missiles, with U.S. officials arguing that this would bring us bargaining leverage. It brought us instead, in a few years, Soviet MIRVs. Recently, the President said at a press conference that he doubted that the Soviets "could expand their military production any place beyond where it is right now" and that "they know they can't match us" in an arms race.

I know of no informed observer of the Soviet Union who agrees with this conclusion. There is nothing to suggest that Soviet military power is a transient phenomenon, or that Soviet leaders are paper tigers who can be cowed into giving us arms control by default. Instead, either both sides will agree to reduce and control nuclear weapons, or both sides will continue to increase, with greater risk of nuclear war through panic or misunderstanding.

Advocates of the development and deployment of strategic defensive systems may also seek support in the scientific projections of the effects of nuclear explosions on the global environment. If technology, either existing or foreseeable, could in fact destroy warheads without nuclear explosions, the world would indeed be a safer place. But a leaky defense, which is all that now can be contemplated, would only stimulate the deployment of additional thousands of nuclear warheads to overwhelm any defensive system that could be created. And since each side would employ worse case analysis, and overestimate the other side's defensive capabilities, the incentives to strike first at a time of crisis would also increase.

The possibility or probability that nuclear war might create conditions incompatible with human existence does not, in my opinion, necessitate a reconsideration of the objectives of nuclear arms control. The findings with respect to "nuclear winter" show that the list of horrors is still expanding. For many years, however, responsible scientists have warned that mankind has developed the ability to destroy itself. The only possible answer under the present regime of independent-nation-states is to control and reduce nuclear arms. The objective of our arms control efforts should still be to preserve a stable strategic balance at the lowest possible level of risk.

Despite the present negotiating impasse, this effort must continue. In my opinion, it can succeed if each side accepts the fact that any agreement must have advantages for both. Neither the United States or the Soviet Union will ever accept an arms control agreement that leaves it relatively worse off than if there were no agreement at all.

The simplest and quickest way to make progress, as I see it, is to end the artificial separation of strategic nuclear weapons into those of intercontinental range and those of intermediate range. The Soviet SS-20s should be treated the same as the Soviet SS-18s and 19s. The fact that they can devastate NATO Europe and Japan but not the United States does not warrant their being relegated to some separate category. Nor does it make any sense to treat ground-launched cruise missiles or Pershing II ballistic missiles as if they were a lesser threat to the Soviet Union than air-launched cruise missiles or submarine-launched ballistic missiles. With intermediate-range weapons included in an overall ceiling, this ceiling should be subject to annual reductions in the order of 10 percent. At the same time, the sub-ceilings contained in the SALT II Treaty should also be subject to annual cuts. This would mean, in a period of a few years, drastic reductions in the most destabilizing systems, intercontinental ballistic missiles with MIRVs, and sharp cuts in total megatonnage.

This, obviously, will not mean the complete eradication of the nuclear danger. Perhaps that can't be achieved in this century or in the early part of the next, but at least we would be moving in the right direction. The scientific data shows us, at a minimum, that the present course is a reckless one.

Senator **Proxmire**. Thank you very much, Mr. Warnke.

First, I want to welcome Senator Sasser. Senator Sasser has been a leader in the Senate on the arms control issue and we are delighted to have him join us as a guest of the subcommittee.

I'm going to suggest that we have a 10-minute questioning and that we go around however many times members want to go around and how many times the panel can hold out.

Let me start off by asking you, Mr. Sagan, you have been challenged here by this illustrous panel. I think that they've agreed—Mr. Murray, I don't think you indicated that there should be no change even in the policies he advocated before but there should be an intensification, if anything, because of nuclear winter in trying to seek arms control and the most effect and persuasive kind of deterrent, and I think the other members of the panel tended to agree.

What's your response to the argument that the nuclear winter thesis should not change the policies that these gentlemen would advocate, although they are different policies that the administration is following at the present time?

Mr. **Sagan**. Well, there are enlightened and unenlightened policies. I hope nuclear winter will strengthen the hands of those with enlightened policies and will encourage a serious reassessment by those with unenlightened policies.

Certainly saying that nuclear winter means that first strikes are self-deterring is not big news to someone who already believes that first strikes are madness—because of the invulnerable retaliatory capabilities in mobile missiles, submarine missiles, and bombers. But there are lots of people who nevertheless consider first strike as something reasonable, who design nuclear war-fighting plans. And the fear of first strike has driven a number of strategic systems.

So I would hope that knowledge of the nuclear winter consequences of a first strike would help to moderate those who have not yet seen the light.

Senator **Proxmire**. So the aggressor would be a victim of the first strike, as you put it, even if there's no retaliation?

Mr. **Sagan**. Yes.

Senator **Proxmire**. Possibly, very probably so?

Mr. **Sagan**. It is an elaborate and very expensive form of national suicide—a compelling first strike. There are cheaper ways to do it if that's the objective.

Then on the question of FEMA, this is large organization of the Federal Government devoted as far as I understand by statute to the contention that nuclear war is survivable and everything should be done to maximize survivability. I think the nuclear winter findings have some relevance to the statutory mission of FEMA, and certainly to the way that FEMA has been carrying out its activities.

There is thirdly a sense in the United States and the Soviet Union that we all knew that nuclear war was terrible. Our capacities for horror have already been saturated. Many people have said to me, "I can't generate much more horror because of nuclear winter. Several hundred million people dying has already saturated my capability for feeling horror. Killing everybody on Earth doesn't generate much more horror."

Well, that is an opinion we can perhaps sympathize a little with for the citizens of the United States and the Soviet Union who in any case would mainly die in an major exchange. But elsewhere in the world, it is very different.

Senator **Proxmire**. Mr. Sagan, let met followup on that right here with a specific question. It's been asserted by Charles Zraket of the MITRE Corp., that nuclear winter renders the notion of a real civil defense program, which is already in disrepute, even more disreputable. Do you believe civil defense is no longer justified or would you concede that it would be of value in a nuclear war begun by one of the smaller countries or in an exchange involving only a few weapons?

Mr. **Sagan**. Well, that fades, Senator Proxmire, into a continuum. Should civil defense be advocated for nonnuclear disasters? Clearly, yes. And how about civil defense in the case that one nuclear weapon is exploded on American territory but no others. Clearly, that would be useful.

Senator **Proxmire**. How about civil defense in the event of the situation that you so well described that you could have 500 to 2,000 megatonnage smaller war—maybe it couldn't happen now but it could happen certainly in the future as proliferation continues—somewhere else, you could have a nuclear winter that would affect the United States but without either of the superpowers being involved?

Mr. **Sagan**. I'm concerned that civil defense has a plainly political objective and that is to assure people—if not to assure them, at least to give them some hope of survivability after nuclear war. The net result is that people then don't worry about nuclear war as much.

When you talk to Soviet planners, which I've done, on why they have given such propaganda prominence to shelter programs, their response is, "Do you want us to tell our people that we can do nothing to save them in the case of a nuclear war?" That is, governments who do not guarantee survivability of nuclear war might be unpopular, for reasons that are not hard to understand. I suspect that what is fundamentally behind the civil defense issue is this political question and not the issue of survivability.

Senator **Proxmire**. Then could you consider any kind of civil defense that would save lives in nuclear winter, for instance by stockpiling food and other things below the surface?

Mr. **Sagan**. Well, let's think of that. Edward Teller has recently proposed that as a response to nuclear winter. He says stockpile enough food for everybody in the country for a year. That is very interesting to think of the working out of it. There are questions of distribution and how would——

Senator **Proxmire**. It would help our dairy farmers in Wisconsin.

Mr. **Sagan**. Especially; but when this question is raised, we have to ask, how does it look from the standpoint of people in other countries if the United States stockpiles enough food for its citizens for a year or more after nuclear winter when everybody else on the planet is almost equally vulnerable and the United States is not stocking food for them? Doesn't this look as if the United States is kissing off everybody else on the planet?

I think there are very deep and worrisome global political implications of such stockpiling of food and other civil defense measures, given the new understanding of nuclear winter. It's a different ball game.

I was going to say before that another major change is that people in other countries now have to face up to the fact that they are tremendously vulnerable in the case of a nuclear war. The difference between killing a few hundred million people and killing a few billion is a very major issue if you don't happen to live in northern midlatitudes, which most of the people on the planet don't.

Senator **Proxmire**. Admiral Gayler, what are the implications of the nuclear winter theory for the military feasibility and usefulness of limited nuclear war? Given the danger of escalation above the climatic threshold, has strategic thinking about how we could fight and survive a nuclear exchange become obsolete?

Admiral **Gayler**. I think they were obsolete already, Senator Proxmire, but certainly if there's any danger of escalation at all and the danger I think is extremely high, then the notion of starting a limited nuclear war, for example, to defend Europe is a real loser. It's not a credible threat. It's not a credible deterrent.

In addition, I think that if we go around the globe theater by theater as I have done, and particularly in the Pacific theater for which I was once responsible, but also in Europe and elsewhere, you cannot find a credible, sensible use for nuclear weapons—not in Asia, not in the Middle East, not in Africa, not in Central America, and quite particularly not in Europe.

The first consequence of an initiative use of nuclear weapons—we start a nuclear war, we try to stop a presumed Russian attack—would be that something more than 1 million, in all probability, friendly noncombatants would be killed. That would fractionate the NATO alliance then and there and the unity of the alliance is the key to its strength.

The second thing that would happen would be an almost certain escalation—you couldn't expect a commander who has reports or enormous explosions going on all around him to give some credence to a message from the enemy saying that these are only tactical nuclear weapons, don't pay too much attention to them, they're sort of benign. They don't go off with a green flash while the strategic ones go off with a flash. They're the same thing and this distinction that we make is an artificial one.

Finally, in a strict military sense, even if somehow by two miracles first use didn't kill millions of noncombatant friendlies and didn't escalate, still in the NATO case we would be at a worse disadvantage after the exchange than before. The reason for that is that we have a much smaller number of far more vulnerable targets—harbors, airfields, depots, and so forth—than the Soviets. So it doesn't make any sense in any of the common military spheres, it doesn't make any sense at sea where we have major dependence on the sea, where we have the big ships and one nuclear weapon equals one ship—it doesn't make sense for us to open up nuclear war at sea. And in space where we are far more dependent for military and civil use on satellites than the Soviets are, it doesn't make any sense at all to use it up there.

So in plain fact, it makes no military sense in any contingency I have been able to think of to use nuclear weapons first whether you choose to call them tactical or anything else.

Senator **Proxmire**. Thank you.

Congressman Mitchell.

Representative **Mitchell**. Thank you. I'm taking a little time to get myself together. This is an incredible experience, that we're sitting in this crowded hearing room discussing in what appears to be logical and cogent terms the possible extinction of mankind. I don't know how people are able to grasp the dimension of what we are even talking about in our civilized usual smooth language. It's an enormously traumatizing experience for me.

I wanted to ask a question. Mr. Murray and I think one of the other panelists raised the idea of strengthening our conventional forces as a deterrent against using nuclear weapons. I'm not at all sure that I agree with that.

During World War II after Pearl Harbor when America's military might was just about decimated, we quickly rebuilt and it was clear that we were going to conquer Japan and yet we used the bomb. We used it anyway. We strengthened our conventional weapons so that we had overwhelming power in that theater of war and yet someone said that we can end the war more quickly by using the bomb. We can save more American lives by using the bomb, and that's history. And I don't understand the logic behind your idea that if we build up our conventional forces this will be a deterrent. I just don't think that's going to happen. I think somebody is going to say, "Let's end it more quickly. Nuke them. Let's save more American lives more quickly. Nuke them."

Have you considered that possibility based on the history of World War II in that theater?

Mr. **Murray**. Congressman Mitchell, the difference is that at the time of Hiroshima and Nagasaki we had a nuclear monopoly. There was no possibility of retaliation with nuclear weapons against our actions, and the President decided that he could save some million casualties and decided to use the weapons.

Today, if we were to try that and the Japanese had nuclear weapons and we were back in the same situation, the result would be very different, and I'm not sure the decision would have been the same.

Representative **Mitchell**. Well, that goes right back to the statement that Admiral Gayler just made. If we go first, are we going to explain to—let's say it's the Japanese or some other group that we're fighting—are we going to explain to them that this is a limited nuclear war and therefore you hold yours down to a limited nuclear response?

Mr. **Murray**. No, I think Admiral Gayler is correct in that. Nobody knows what would happen with the use of a first tactical nuclear weapon.

Representative **Mitchell**. And out of that ignorance will we use it?

Mr. **Murray**. I do not know. I cannot speak for the President. But using them would be extremely difficult—that is the reason, Congressman Mitchell, that we need strong conventional forces, so that we are never forced into the position that that's our only choice.

Representative **Mitchell**. Forgive me for being the nonexpert here. I think the only real answer is to work for peace.

Mr. **Murray**. Will, I agree with that; that is the objective.

Representative **Mitchell**. That's the only real answer to prevent this dreadful chapter in the history of mankind.

Mr. Sagan, on your charts you show the possibility of a nuclear winter lasting as much as a year with all of the dreadful implications of that duration of that year. What about after the nuclear winter? After that 1 year in its worst-case scenario, 1 year, what would be the long-term effects beyond that 1 year of the winter? Are we talking about a decade of ill effects, if we survive? Are we talking about 20 years?

Mr. **Sagan**. Congressman Mitchell, that 1-year duration of nuclear winter was a very conservative calculation. When a fully interactive calculation is done, in which the perturbed structure of the atmosphere determines the time for the particles to get carried out, it looks as if the duration would be considerably longer than a year.

Some recent work by Alan Robock at the University of Maryland involving feedback effects, polar snows and ice floes in the Arctic Ocean, suggests an additional reason why the duration might be considerably longer than I have said. I would not be surprised if the recovery to ambient conditions took many years or even a decade.

Now when the temperatures return, assuming they do, to the usual conditions, what would the world be like? It seems very clear that if there have been massive extinctions—never mind humans—of plants and other animals, that the ecology of the planet is changed. But life on Earth is a kind of tapestry. It's a fabric. And if you pull out a number of the threads there's a chance of unraveling the whole business because the organisms' life process are so tightly interwoven.

So the possibility that there are very long-term, very serious biological effects is certainly there, but we are too ignorant to be able to trace out in any detail what they would be. My guess is that while there are factors which make the biology of the planet resilient and tend to restore things, that nuclear winter would be such a severe blow to life on the planet that things would be dramatically changed, although we are not able to say by how much.

Representative **Mitchell**. I guess that's exactly what I was thinking, that even though you look at the resiliency of nature to come back to something that may be comparable to what it was before nuclear winter, that the damage we will have done to the ecological ordering of things will make the world never the same again. I'm not talking about 10 years. I'm saying never the same again.

Mr. **Sagan**. In the study of the hisotry of life on Earth, paleontology, there have been times of massive extinction discovered. Sixty-five million years ago, at the boundary of what is called the Cretaceous and the Tertiary epochs, enormous numbers of species were extinguished, including every dinosaur. They were, until then, the dominant life form on the planet. Something like that is possible—of course, it's a very different world now than from when dinosaurs were ruling it. But the possibility of something like that cannot be excluded.

Representative **Mitchell**. Thank you.

Senator **Proxmire**. Thank you.

Senator Sasser.

Senator **Sasser**. Thank you very much, Senator, and I want to commend you, Senator Proxmire, for taking the lead in holding these hearings here today. I think they are extremely important and what you have developed today from this panel of very distinguished experts is some most compelling testimony which I think is highly informative and at the same time deeply disturbing, and this is a great service I think to the country, perhaps, Mr. Sagan, a great service to all mankind—to get this information out and get it on the table so that at least some opinion leaders in our society and our Government can see it and hopefully react in a rational way.

Mr. Sagan, we engage in a doctrine called mutually assured destruction of man. The thesis of that is that we keep our nuclear arsenal so powerful and so invulnerable that this would discourage the Soviets from striking us and vice versa. I want to be sure that I understand what you said today.

If this scenario of a nuclear winter is accurate, then this tosses the theory of mutually assured deterrence into a cocked hat. In other words, the aggressor nation or the first strike nation would suffer the consequences of nuclear war even if they took no nuclear hits on their territory. That's an accurate statement, it is not?

Mr. **Sagan**. Yes. To give a metaphor I've used before—it's not perfect, no metaphor is, but it gives a sense of the realities—here's a way to look at the global confrontation between the United States and the Soviet Union: There are two implacable enemies standing in a room which is ankle deep in gasoline. One of them has 9,000 matches and the other has 7,000 matches. They are debating whether there is a match gap.

Senator **Sasser**. That's a very convincing illustration, I might say.

Mr. Murray, I noted that you and I think Admiral Gayler agreed and also Mr. Warnke agreed that we needed to strengthen our conventional military forces. I don't know whether I agree with that or not. We are engaged now in apparently a long-range program to increase our conventional forces. We have increased defense spending in real terms over the past 3 years approximately 33 or 35 percent, if I'm not mistaken.

In your estimation, Mr. Murray—and I'll address this also to Admiral Gayler—what would constitute an adequate and sensible growth in a conventional defense budget?

Mr. **Murray**. I think the greatest uncertainty in that, Senator Sasser, and the reason I can't give you a precise answer, is because so much depends on what contributions we can expect from the NATO allies.

Senator **Sasser**. That was going to be my next question.

Mr. **Murray**. The NATO allies have been unwilling thus far to face up to the real requirements of a credible conventional defense. I believe if they continue to do that, it is unlikely that we, by ourselves, could generate a credible defense against an attack in Europe.

However, it seems to me that the requirements are on the order of a 5-percent real growth in the national defense budget for perhaps a decade. There's a very large——

Senator **Sasser**. On the part of ourselves and our NATO allies?

Mr. **Murray**. Yes. There's a very large imbalance in conventional forces between the Warsaw Pact including the Soviet Union and NATO including the United States, that I think would take some time to redress. I think that is something we should be doing. I am not in favor of throwing up our hands because we get inadequate contributions from the allies. I think we have to keep working to increase their contributions because this is immensely important. It's clear we depend on them as much as they depend on us.

Senator **Sasser**. Would you like to address that question, Admiral Gayler?

Admiral **Gayler**. Yes, I would, Senator Sasser. I think that how much money we spend on it is probably the worst possible yardstick with which to evaluate defense. It's perfectly clear that you could waste money terribly both in contracting procedures and in many other ways and even more so in buying things that you not only don't need but are actually dangerous tools, like MX and many of these other systems.

Now money is not the best yardstick. What you do with it is the right yardstick, and for that the lead from every thoughtful senior that I know is that you should first describe what it is that you intend to do with your military forces and then tailor your forces to do that, rather than the other way around.

I think it is perfectly clear that in broad strategic terms the United States with our allies have to be able to hold ground in certain places like Europe, Korea, and possibly elsewhere, without resort to nuclear weapons. We ought to be able to keep open the sea and airlanes that link together the West. We have to, in some circumstances, be able to protect and sustain fighting power at vast distances and I think today we have to face up to the fact that international terrorism exists, and together with the civil authority, we have to be able to deal with that.

These are broad military objectives on which we should tailor our forces, not buy forces and they try to figure out what you're going to do with them. In short, we have to make choices. In my judgment, we have been putting so much command attention and so much money into nuclear forces that we have even now, with this budget level, serious military shortcomings. I think we have to be far better oriented toward the future. I'm not enthusiastic about battleships and building a lot of thin-skinned surface vessels in an era when I think it is perfectly clear that submarines and high performance airplanes and space vehicles will dominate the purpose.

Finally, I think we have to talk a lot more than we have, and do a lot more than we have, about military people. Perhaps the most important single military capability that we could possibly have is smart and capable generals and admirals and other leaders, and we neglect those people.

What I'm saying—and there isn't time to testify on all of this—is what we need is a clear sense of military reform, not even necessarily a large expenditure.

Finally, I'd like to comment on your remark about mutually assured deterrence as a policy. In my judgment, it's not a policy. It's a situation that we're in and we can't get out of it, no matter what we try to do, until we have made far-reaching changes in the character of the nuclear establishments all the way around the world. I think we should make those changes. But it's not a policy we have. It's a situation that we're in.

Senator SASSER. Mr. Warnke, what is the state-of-arms talks at this particular moment? This is a political season, as you know, and the administration has been under attack or criticized, I would say, for the last 2 or 3 years because of what some perceive and I perceive to be a lack of willingness to move forward in arms negotiations and mutual arms talks with our chief adversary, the Soviet Union. I'd like to get your statement today as to just what you perceive to be the state-of-arms negotiations and the nuclear disarmament negotiations at this particular moment.

Mr. WARNKE. I'd have to say, Senator Sasser, that the state is nonexistent, that there are no talks on controlling nuclear arms. In my opinion, there have not been serious talks since the beginning of the Reagan administration. I think that the Reagan administration came into office feeling that they had a mandate to downplay arms control and have an unlimited strategic nuclear buildup.

Now I think force of public opinion, both in Europe and in the United States, led them to initiate both the intermediate-range nuclear talks and the START talks, but I don't really believe that priority was placed on them. We weren't prepared, for example, to trade off any of the new weapon systems to which Admiral Gayler referred. In connection with the MX, for example, it was presented by the administration as a bargaining chip, but then both the President and our chief strategic arms negotiator said that the MX would not be traded away and that with the smaller surviving numbers of weapons the MX would have to be included. If we take a look at the proposals that have been put forward, at least that have been made publicly available, they did not provide any sort of an acceptable basis for constructive negotiation.

The initial proposal with regard to strategic arms reductions in the START talks, was a cutback to 2,500 ICBM warheads. Now at the same time, we would build up our MX so that you would have roughly 400 surviving Soviet missile silos with an average of about 6 warheads each; 400 with 6 each, 2,400 all total. Against those 400 silos, we would deploy 1,000 MX warheads which would give us a genuine preemptive strike capability against the Soviet ICBM force.

Now similarly, since the Soviets would have built up their SSX-24, we'd be giving them an assured preemptive capability against our surviving ICBM's.

It was a proposal that if the Soviets had accepted we would have had to say "April Fool." We weren't serious. We'd take it back. We couldn't have taken yes for an answer.

Now I think it's clear from the remarks that the President continues to make that he still believes in the arms race theory of arms control, that the Soviets, if we continue to build up, will have no choice but to knuckle under because they can't increase their military budget. That is contrary to every bit of the history of nuclear arms. Either both sides will reduce or both sides will build up. And if we accept that, and accept the further proposition that the only purpose of nuclear weapons is to see to it that they can't be used, we will have no chance, in my opinion, of success in nuclear arms reduction talks.

Senator **Sasser**. My time is up, Senator.

Senator **Proxmire**. Go right ahead.

Mr. **Sasser**. If I could just ask one brief and very pointed question. I judge from the testimony of this panel today that you are unanimous in your opinion that the MX missile system housed in the old Minuteman silos is a destabilizing weapon which actually lessens the security of the United States and our people rather than increasing it. Is that a fair assessment?

Mr. **Murray**. Yes.

Mr. **Sagan**. Yes.

Mr. **Warnke**. It certainly is, Senator.

Senator **Proxmire**. You all nodded. I take it that Mr. Sagan, Mr. Murray, Admiral Gayler, and Mr. Warnke, you all agree with that; is that correct?

Mr. **Warnke**. That's correct.

Admiral **Gayler**. Yes.

Mr. **Murray**. Yes.

Mr. **Sagan**. Yes.

Senator **Proxmire**. Mr. Murray, you indicated that the world has changed greatly since Hiroshima and Nagasaki and we had a monopoly. However, just the other day there was to me a very startling and shocking revelation of a conversation that was disclosed finally after 30 years I guess between the President of the United States, then President Eisenhower, and the National Security Council in which the President, and the Secretary of State, and the head of the National Security Council all agreed we would use nuclear weapons against North Korea if they invaded South Korea. They also indicated we might use nuclear weapons against China. At that time China didn't have nuclear capability.

Now I think maybe in 10 years or so we'll know what was going on between the President and the National Security Council with respect to Vietnam.

But isn't it perfectly possible that this country—and certainly the Soviet Union more than this country I would think—might contemplate the use of nuclear weapons against a country that didn't have the capability of retaliating? If that's the case, doesn't the nuclear winter thesis act as a very helpful restraint under those circumstances?

Mr. **Murray**. I hope it does, Senator. I can't speak for the likelihood of that. Of course, it depends upon how many weapons were to be used against a small defenseless country. The use of even 500 warheads against a country that had no military capability to retaliate speaks very strongly of overkill, I think. That doesn't mean that I suggest there is no risk of that, but I'm not sure the scenario is likely to occur.

Nonetheless, the thesis of nuclear winter should help to diminish the possibility that that could occur.

Senator **Proxmire**. Now, Admiral Gayler, I think at least Mr. Murray, Admiral Gayler and Mr. Warnke have spoken about the importance of providing increased conventional strength if we're going to go to the first use doctrine, and two of the members of the panel have indicated that either they disagree with that or they are not sure about it. I agree with it. I think we have to have greater conventional strength and the first use doctrine. But it seems to me that that's not the only alternative.

Why can't we also consider a more vigorous and more effective arms control policy? It seems in all of our military strategy we are less inclined to view that which seems to me is by far the best military strategy in the nuclear world is to work for arms control and try to achieve that and then maybe you wouldn't have to perhaps rely that much on conventional forces.

Admiral **Gayler**. Senator, without going into detail about the——

Senator **Proxmire**. Let me just interrupt to say that I'm talking about arms control with respect to conventional weapons as well as nuclear weapons.

Admiral **Gayler**. I understand. Without going into detail about the defense of Europe, I believe it is entirely practical, given certain elements of military and political reform which may well result in forces not larger than we have now but simply better suited. In addition, I would agree with you that there are real prospects, if we were ever to take them seriously, in a mutual and balanced force reduction process in order to reduce the risk of a conventional war starting in Europe by means of mutual reduction of conventional forces.

Finally, I think there's value in agreement simply to redeploy forces out of the immediate striking range of each other. The Soviet tanks which are so far forward and are of concern to the NATO commanders because of the short time lines as it's called, the fact that they can move faster than the countervailing forces of NATO can be deployed against them—if those tanks could be moved back as part of some general agreement, in my mind it wouldn't affect the military position of the Soviet Union in Eastern

Europe and there would be plenty of room for them to be there but it would greatly reduce this real concern of the commanders that the Soviets could move their forces faster than we can array against them.

I think what I'm saying is that I agree, there is prospect for useful arms control in conventional forces as well as nuclear, but it has to be coupled with what I advocated earlier and that is that we have a clearer understanding of what the military things are that we need to be able to do and design our forces to do that. How much we need will, of course, a function of how much our opponent has and that we may well be able to limit by agreement.

Senator **Proxmire**. Thank you, sir.

Mr. Warnke, some analysts have warned us that the nuclear winter findings may have a pernicious effect. An accelerated arms race to develop low-yield, high-accuracy arsenals, a large increase in plutonium production, a strengthened push for ballistic missile and air defense, and a highly destablilized overall situation caused by no one knowing any longer if they have an effective deterrent or not. In the absence of significant new arms control agreements, could the response to the nuclear winter findings lead to a more precarious balance of terror? Does the administration policy seem to be heading in this direction?

Mr. **Warnke**. I really cannot predict the way in which the administration will head, Senator Proxmire. I am not encouraged by indications to date. As I said in my opening comments, there is a risk that the findings with respect to nuclear winter may be used by advocates of smaller, more precise, more surgical, more accurate nuclear weapons. I don't think that that would be a logical response.

In my opinion, all that would do would be to lower the nuclear threshold, to blur the distinction between conventional weapons and nuclear weapons, and nonetheless, to present the same possibilities, the same risks, of escalation. For one thing, if we develop nice, small, clean nuclear weapons and the other side has nothing but big, ugly, old-fashioned nuclear weapons, then the logic of this particular approach would be to build twice as many and give half of them to the Soviet Union. I don't think that's a course that anybody is going to follow. But as I say, it seems to me that as a response to the findings with respect to nuclear winter, developing new types of nuclear weapons would be entirely irrational.

Similarly, it seems to me that reliance on ballistic missile defense as being the answer would be self-defeating. There is no existing technology that would give us anything like an effective defense against nuclear weapons from the other side.

Senator **Proxmire**. Are you familiar with the thesis of General Gallors and Trane? They had an article in the Wall Street Journal some time ago about how people had misunderstood the trend in nuclear weapons and nuclear weapons were moving in this direction, greater accuracy, much lower yield, which they argued would make it possible to fight a nuclear war very similar to our conventional war—a lot shorter of course, more effective, but none of the colossal effect on very large populations.

Mr. **Warnke**. I disagree with them in two respects. In the first place, that is not the way in which nuclear weapons are moving.

We have, for example, now deployed ground-launched cruise missiles. That warhead, I think, is 200 kilotons as compared with the 40 kilotons on the Polaris submarine. I don't think that the MX warhead is going to represent a significant reduction in destructive capability and certainly the same is true with the Soviet SSX-24's and the other weapons that are currently being developed.

Second, as I said earlier, the entire concept of trying to fight a rational nuclear war, in my opinion, is basically irrational because you would not be able to control the escalation. And if you're going to make your weapons more and more like conventional weapons, let's build better conventional weapons rather than start down what I regard as the slippery slope of an initially limited nuclear war that can't stay limited. Once you cross that nuclear threshold, which side is going to be willing to lose the nuclear war? Which one is going to exercise restraint? The one who's winning might. The side that was losing would not.

So I find the article, as I found it when I read it, totally unpersuasive and I think more directed toward budgetary considerations than toward any kind of logical considerations.

Senator **PROXMIRE**. Admiral Gayler.

Admiral **GAYLER**. I agree totally with Mr. Warnke, and I would like to go a little bit into the grain of the purported military operations. I have already talked about tactical nuclear weapons at sea and our being dependent on the sea. I was an active fighter pilot for about 20 years. I can assure you that fighter pilots will not fly in an area where nuclear weapons are likely to be used against aircraft because they blind you. Fighter pilots look around and you're not happy being blinded in a high performance airplane with the necessity of landing on a carrier again. They just won't do it. So you will have that problem to contend with.

In the land battle, I think what is neglected in this highly theoretical idea is the problem of targeting. Now what a box of B-52's could do is roughly comparable to a small nuclear weapon, not radioactive, of course, and not exactly the same, but comparable. Using the entire resources of the Pacific Command Intelligence, which are the best in the world, in my judgment, not interrupted by enemy action and with plenty of time, we were hard put to sensibly target five targets a day. Now to suggest that anybody can sensibly target in an hour, or 2 hours, or even a couple of days hundreds and hundreds of tactical nuclear weapons just staggers the imagination. I think the vast majority of them would go off and be either totally useless or they would kill noncombatants.

Senator **PROXMIRE**. Mr. Sagan, the finding that a nuclear winter would follow a nuclear war is so enormous in its potential ramifications, and yet seems so plausible an outcome of the dust and smoke caused by nuclear explosions and fires that it makes one wonder: Why did it take so long for the scientific community to understand it, and what does the long delay in gaining this understanding say about the state of nuclear science and the way the Government conducts research in this area?

Mr. **SAGAN**. On the one hand, there have been prophetic, seat-of-the-pants remarks about the possibility of extinction of the human species from nuclear war, made not just by novelists like Nevil Shute, "On the Beach," or Jonathan Schell's first book, "The Fate of the Earth," but also by Andrei Sakharov and Edward Teller, of all people, who in February 1947 said: "It is not even impossible to imagine that the effects of atomic war fought with greatly perfected weapons and pushed by the utmost determination will endanger the survival of man." So there has been that sense in the scientific community that it might happen, but never a calculation showing it was the case. Indeed, the whole notion had been considered disreputable.

As to why the calculations weren't made, I don't know. It's a very interesting question. There are agencies of this Government and others whose statutory responsibility is to inform the national leaders what the consequences of nuclear war would be. That they did not sufficiently look into climatic effects seems the appropriate conclusion, and I wish to we had come upon it earlier. We could have done this calculation 5 or 10 years earlier. It never occurred to us. I wish it had.

The one conclusion I would draw from this is that we have missed a lot of things. You made a list of them earlier. You talked about radioactive fallout, and about breaching the ozone layer, and the attendant UV flux, nuclear winter, EMP, and so on. But this then raises the question of what else we overlooked. What other consequences of nuclear war have we not been wise enough to foresee?

It's an unprecedented event, the kind of major nuclear war we're talking about, and it seems to me that we should be very cautious in the face of the history of our ignorance on this subject.

Senator **Proxmire**. Is there any effort on the part of you, Mr. Sagan, or others, to probe what these other consequences of nuclear war could be?

Mr. **Sagan**. Yes. Our group is continuing to work on this issue. The nuclear winter, I suspect, has so many ramifications by itself, it will——

Senator **Proxmire**. I mean beyond the nuclear winter.

Mr. **Sagan**. I understand. It's hard to know what those new things are. Some day somebody will have some idea, the light bulb will become illuminated, and probably we will hear of some other consequences. It's hard to know specifically how you go about looking for them. But there are agencies with vast budgets who I would hope would now be devoting significant attention to trying to flush out the other unanticipated consequences of nuclear war. There must be some.

Senator **Proxmire**. One finding that you made that really astounded me and I think it astounded a lot of people is that the nuclear winter could be triggered at such a relatively low yield, that is 500 to 2,000 megatons, which as you pointed out is a small fraction, less than 10 percent of the nuclear capability of the Soviet Union and the United States, 2,000 down to 500. There's been a vigorous dispute with your proposal that follows logically from that that we should try and negotiate down—Mr. Murray did that this morning—we should try to negotiate down to that level.

It seems to me it would be very hard to do it and especially to verify it. How in the world—if you go down to 500 megatons, for instance. I assume the United States and Soviet Union said that had all the 500 which they couldn't do because it's the other nations too—I don't know how you get France involved and China—but say we were able to get both nations down to 250 megatons and then they did and they agreed with it. How in the world could we verify that? Wouldn't stockpiling under those circumstances be very easy and wouldn't that be an enormous temptation on the part of one or the other to maintain a tenfold advantage and be the superpower, particularly on the part of the Soviet Union?

Mr. SAGAN. Well, it's a very important and complicated question and I will make some response to it, but I think Admiral Gayler, because of the breadth and diversity of his background, has more important things to say about it.

We have spent a period of time, roughly 30 years, getting from very few nuclear weapons to the tens of thousands that we have today. That was done unilaterally by both the United States and the Soviet Union. To get back down to those low levels, it's hard to imagine it happening in a shorter period of time. So we are talking about decades, even if there is a strong political will.

Now we live in a time of enormous suspicion and mistrust between the United States and the Soviet Union. Each escalation by one side provokes an escalation by the other side. That's a very different kind of international climate than the one I can imagine in which the nations are engaged in a kind of peace race.

Now the Soviets have, with a number of treaties negotiated and unratified, proposed or agreed to onsite inspection. It's very clear if you get down to very low levels of nuclear weapons you would have to have onsite inspection. There are a set of proposals on how to do it. Admiral Gayler's deep cuts is one in which the early stages, the first few factors of two that Congressman Mitchell talked about, could be done in a nonintrusive way. What Admiral Gayler imagines is some central bilateral or multilateral depository in which the fission triggers or warheads of both nations are delivered and in fact converted into electricity—the ultimate in beating swords into plowshares.

Senator PROXMIRE. Converted into electricity? That's fascinating.

Mr. SAGAN. In nuclear reactors, it certainly can be done.

Senator PROXMIRE. I'll sell my utility stocks.

Mr. SAGAN. And the early stages of weapons deaccessioning can be done with very little worry, it seems to me, on the verification issue. The further into the process you go, the more difficult is the verification issue. But it is not insuperably difficult. Suppose the same kind of energies and devotion and technical expertise and national resources were devoted to undoing and reversing the arms race as have gone into building it up. I'm confident that the inequity and devotion on both sides would be adequate for this challenge.

Senator PROXMIRE. Well, that reminds me of an old saying by a New York sports reporter who was observing Rex Barney, who was a speedball pitcher beyond compare for the old Brooklyn Dodgers. But he was terribly wild and the sports reporter said, "If the plate were high and outside, that Rex Barney would be the best pitcher in the league."

Unfortunately, the plate isn't high and outside in this case and I think there always would be more energy going into, unfortunately, building up a military defense, under all kinds of rationalization, than the kind of energy you've called for here.

Mr. **Sagan**. Well, Senator Proxmire, the reason for the nuclear arms race has been the national security of the United States and the Soviet Union. If we recognize that it is an opposite kind of race that is essential for the national security of the United States and the Soviet Union, then I believe that every rational person would be willing to support a reversal in the arms race.

Senator **Proxmire**. What would keep China, what would keep France—particularly China—from under these circumstances saying, "Look, the United States and Soviet Union are down to a couple hundred nuclear weapons; we have the capability of moving ahead, and why don't we become the superpower?"

Mr. **Sagan**. I stress that when we talk about getting down to levels which are comparable to the forces of Britain and France and China that those nations must be involved. If they would prevent adequate verification, then the levels would have to be frozen at a higher level. But China has been very clear as recently as 1 year ago in the United Nations about its approach to this issue. It said that when the United States and the Soviet Union showed some serious interest in reducing their strategic stockpiles, then China would be happy to enter into negotiations. But, said China, there is no hint that the United States and the Soviet Union are interested in a reversal of the arms race.

My sense is that if our lives depend on it, these difficult shoals can be negotiated.

Senator **Proxmire**. Admiral Gayler, Mr. Sagan indicated that you might be interested in commenting on this.

Admiral **Gayler**. Thank you, Mr. Sagan. The first thing I'd say, of course, is what I think we see as the first stage, the first and extraordinarily important stage of getting to mutual security is the minimum invulnerable deterrent against nuclear war. Whether that be at the 250 level or the 400 level or some other, if it is an adequate deterrent and it doesn't matter if the other fellow has squirreled away twice as much because it is still enough to destroy him if it is invulnerable.

I would like, however, on the basis of experience, to talk a little bit more about the intelligence process. Verification is a part of the ongoing intelligence process which goes on day in, day out, whether or not we have treaties. Everybody knows we get good pictures from satellites. For reasons which are extremely good, we do not talk about other intelligence methods that we have. But I think you can be assured that the satellites are only the tip of the iceberg.

There is in fact a 1-percent chance that we have a mole in the Kremlin and we know everything that goes on there, and the Soviets have to reckon with that chance, small as it may be. There's a 99-percent chance that if they build a replica of the Capitol on the banks of the Moscow River we would get a picture of it. The whole intelligence process lies somewhere along that continuum.

The point of all this is they could never be certain. They could never be certain that any squirreling away sufficient to make a difference wouldn't be detected.

Finally, I think it should not be overlooked, particularly not here, that this process of destruction of nuclear weapons by turning them in and visibly destroying them out of existence, converting the fissionable material to generation of electricity which, by the way, is totally consistent with the process Mr. Warnke has been advocating—that process itself would have a profound effect.

Can you imagine the television cameras of the world when they first saw nuclear weapons with the stars and stripes and hammer and sickle turned in for destruction? And that process continuing over years could not fail to affect the political relationship.

As an illustration, let me ask, what has happened to the Chinese missile threat, the Chinese missile threat that we actually built an ABM to defend against? At least that was part of the justification. Have the Chinese not got any missiles? No. They've got more missiles now than they used to have. The only thing that's happened is we have changed our perception of the Chinese. I think if we were actually to reach these minimal levels compared to the thousands and thousands of warheads and the threatening rhetoric and all the rest of it, the political change would be enough so that we would be far more assured of our security than we are now.

Senator **Proxmire**. Thank you, Admiral.

Mr. Murray, you indicated there should be no change in policy, at least in the policies you advocate, because of nuclear winter. Let me ask you about this. If the nuclear winter findings are valid, should the strategy of counterforce attacks against Soviet military targets be ruled out? In your response, would you define briefly what a counterforce attack is and also identify the U.S. weapons intended to carry out this policy.

Mr. Murray. Let me make clear, in case there's any doubt, that what I meant to say in my prepared statement was that our policies in the absence of nuclear winter should be the same as our policies with nuclear winter. The disaster is sufficiently bad in the case without nuclear winter that the addition doesn't make any difference in the kind of policy we should have. That was not an endorsement of the administration's current policy.

The idea of a counterforce attack strikes me in many ways as illogical. What most people think of as a counterforce attack, at least in retaliation, is an attempt to strike Soviet missile silos in addition to other important targets—relatively soft military facilities, command control bunkers, and things of that sort. But the idea of striking Soviet silos after they have first fired at us strikes me as madness, insanity.

If the Soviet Union intends to strike us, they may or may not use all their silo-based ICBM's in that strike. So presumably there may be some left in the silos, kept in reserve. However, if we were to then fire at all those silos in an attempt to get the remainder, I think the chances of the Soviets leaving their missiles just sitting there rather than launching them out from under our attack is very, very small. They would be entirely prepared and watching for our retaliatory strike. The idea that we could surprise them in that kind of situation strikes me as just implausible.

Therefore, counterforce against silos in retaliation, I think, would largely result in a great wastage of warheads from any military point of view.

As for a definition of counterforce—I'm sorry I forgot to answer that—that is generally taken to mean a strike at the enemy's military facilities as opposed to population or industrial capacity.

Senator **Proxmire**. Now what about countervalue attacks against industrial targets? Should that option be ruled out and, again, define countervalue attacks for us in your answer and define the weapons intended to carry out that policy.

Mr. **Murray**. Countervalue normally refers to destroying the economic power of the other side and thus involves strikes on industry which inevitably involve strikes on cities of all sizes. Incidentally, a counterforce attack is also very liable to involve cities. For example, one of the tactics most likely to be used against the bomber force is a barrage of the area in which the bombers could be at the time the missiles arrive. If the Soviets were to use that tactic to get the B-52's coming out of March Air Force Base, for example, there goes Los Angeles. So it isn't as if a counterforce attack could be a pure surgical strike.

When you ask should it be ruled out, as a matter of deterrence, I think we need a credible policy of targeting. It seems to me that the targeting of cities is not only immoral but probably less persuasive to the Soviets than the targeting of their military capacity, particularly conventional forces and nuclear stockpiles. I think that we should have an announced targeting policy that would convince the Soviets. I believe they value military power more than their citizen, and that should be the kind of thing we should target. However, I would hope that by having an adequate deterrent there would never be a need to execute that targeting policy.

Senator **Proxmire**. Admiral Gayler if counterforce and countervalue attacks are not viable options what nuclear options remain for the President?

Admiral **Gayler**. I think the President has only one nuclear option and that is to possess, to own enough nuclear weapons to have an assured destructive capability as a second strike against anybody who attacks us with nuclear weapons. Whether or not to extend that umbrella to allies under some circumstances is a judgment I don't think you can make without the specific circumstances, but that I think is what the President has.

Now what is deterrence? To elaborate a little bit on what Mr. Murray just said, I think if you try to define a hierarchy of things most likely to deter the Soviet Union leadership you would define first it's their personal lives. They don't want to be killed any more than the rest of us. The second would be the control of the Communist Party apparatus in the country and the military and everything else. The third would be the military commander and control and the military forces. The fourth would be their industrial capacity. And the fifth, the Soviet people as a whole.

But to me, the whole question is a little bit beside the point. At our present levels, as I said earlier, we have so many warheads and they have so many warheads that targeting choices are not really made. Everything is targeted more or less, whether we declare we don't target cities or they declare that they will not target cities, the fact that you target industrial capability guarantees that you will target cities.

Senator **Proxmire**. Mr. Warnke, you're the veteran arms control expert. You were head of the Arms Control Agency. In my judgment, you're the outstanding expert in this area in our country. We spend very, very little on arms control compared to what we spend on deterrence or any other military strategy. As I understand it, we have more people in military bands than we have in the Arms Control Agency. We spend something like $20 million a year for arms control compared to $30 million a year for a single fighter—just one fighter plane.

In your judgment, can we and should we substantially increase the resoures in arms control? Would that help?

Mr. WARNKE. I think unquestionably, Senator Proxmire, that some modest increases in the budget of the Arms Control Disarmament agency would help, but the real problem is the failure to use our arms control resources, the failure to have a national policy that puts priority on arms control.

I know from my own experience, for example, that if all you have is two sets of negotiators facing one another across a green felt table in Geneva, you're never going to get an agreement. What is required is high level involvement. The Secretary of State has to be involved. The President of the United States has to be involved, and they have to regard this as a priority item. So then they can use the resources that they have, such as the experts in the arms control disarmament agency. But just to increase the budget of the agency would be a waste of money. All you would have is a more expensive agency that still wasn't being used because it was not regarded as being that much of an importance to the national security.

Senator PROXMIRE. Well, my question—you're absolutely right and I didn't frame my question properly. My question should be, if we had that kind of involvement on the part of the President, if we had that kind of emphasis on arms control, in your judgment, would we need substantially to increase resources and staff and personnel and capability to do the job?

Mr. WARNKE. In my opinion, under those circumstances, we would, Senator Proxmire, because you could undertake so many valuable initiatives that you obviously would need a big increse in the amount of staff and the amount of backup. For example, discussions have been taking place about whether deep cuts are enough and what kind of cuts and how low could you get down before running into problems with regard to third countries and possible vulnerability of the surviving forces.

Now accompanying these reductions, what you need is other steps that would insure the preservation of stable deterrence at the lowest possible level of numbers and risks. That means a number of other initiatives. For example, getting really serious about anti-satellite talks and trying to deal with that particular problem. The completion of a comprehensive test ban. We're within certainly no more than months of being able to complete a test ban treaty if we're really serious about doing it. That would be a vey powerful measure of nonproliferation because it would be an international treaty. You could get other countries to sign on. Both the Soviet Union and the United Kingdom have been participants in these talks and if they and the United States were to foreswear forever any tests of nuclear weapons, we would be able to marshal world opinion against anybody else getting into the nuclear weapons business.

President Eisenhower put forward a proposal to cut off production of fissile materials for weapons use. That's still on the international bargaining table, but we're not pursuing it.

Now if we were to pick up some of these initiatives, we certainly could use trained experts, capable backup staffs, and you would need a very substantial increase in the arms control budget. It might still not approximate anything like the cost of some of the frills we have in the defense budget, but it would be money very, very well spent.

Senator Proxmire. Mr. Warnke, what are the arms controls implications if counterforce and countervalue options are eliminated? Should the weapons be scrapped unilaterally or should we negotiate the matter with the Soviets? If the Soviets refuse to agree to eliminate these weapons, should we keep them even though their use is ruled out?

Mr. Warnke. I don't think you can rule out counterforce or countervalue weapons because I think they are all counterforce or countervalue weapons. Even if you weren't aiming directly at the military resources of the Soviet Union, targeting the cities, targeting Moscow, for example, would have a very substantial effect on their ability to conduct a government and certainly conduct it during war.

So I really think that these distinctions aren't relevant in the area of nuclear weapons. I can think of countervalue and counterforce in conventional weapons terms, but I think the consequences of nuclear strikes are just so differenct from the consequences of conventional strikes that I find the distinction largely an academic one.

Senator Proxmire. Mr. Murray, my problem here is you keep these weapons it seems to me the only way we can use them without committing suicide, which none of us want to do—I'm not sure I understand your response to my question about counterforce and countervalue policies.

Wouldn't using such capabilities cause a nuclear winter and doesn't that indicate that we should reconsider the policies?

Mr. Murray. I think the reason that we have the weapons is to deter Soviet use of those weapons. I think if the war ever occurred, then you would have to face the question of is Mr. Sagan right and would we have nuclear winter. I believe that we would.

Senator Proxmire. Say that again.

Mr. Murray. If a major thermonuclear exchange occurred, I see no reason why Mr. Sagan is not right and you would have nuclear winter. You wonder what the alternative to that is. Should we unilaterally disarm, get rid of our weapons? That would be a complete concession and subjugation of the United States to the will of the Soviet Union. Surrender is always one possibility. I would hope we wouldn't have to go to that.

Senator Proxmire. I'm not implying that in the least. I'm not saying get rid of everything. I think we can just get rid of the weapons that we don't intend to use because of this kind of situation. It seems to me we still have—you indicated some options to the counterforce and countervalue.

Mr. Murray. If you say no counterforce and no countervalue, that means no nothing, as far as I can tell. I don't know what is left. Striking the enemy's military capabilities is counterforce and striking anything else, particularly industrial capability, is countervalue. I think what I take you to be saying is suppose we give up the idea of ever firing a nuclear weapon. The danger of that is would we then be able to deter the Soviets from starting a nuclear war? The brightest ray of hope I see is the work of Mr. Sagan in that perhaps it will persuade leaders on both sides that we really do have a serious problem that is in neither side's interest, and perhaps that will trigger actions that we have been unable to inspire over the last 30 years of trying.

Senator **Proxmire**. Doesn't this make it very obvious that as a matter of simple self-preservation that we should both try to reduce the stockpiles below the level of triggering a nuclear winter?

Mr. **Murray**. It makes it obvious to me, but that's not important. The question is, Is it obvious to the Soviet Union?

Senator **Proxmire**. Well, it should be obvious to the Soviets and everybody else.

Mr. **Murray**. Is it obvious to the Soviet leadership and is it obvious to our leadership?

Senator **Proxmire**. It's obvious. Their scientists are involved in it just as Mr. Sagan is, and they seem to have come to the same conclusion.

Mr. **Murray**. People don't always listen to scientists.

Senator **Proxmire**. Mr. Sagan is finding that out this morning. Mr. Sagan, is there indication the Soviet Union leadership believes this thesis?

Mr. **Sagan**. I was told at a meeting at the Vatican on nuclear winter last January by the leader of the Soviet delegation, Yergeniy Velikhov, Vice President of the Soviet Academy of Sciences, that he personally had given extensive briefings on nuclear winter to Defense Minister Ustinov and Foreign Minister Gromyko. I was unable to assure him in return that extensive briefings had been given to Secretary of Defense Weinberger or Secretary of State Shultz, although at least the Director of the Arms Control and Disarmament Agency, Mr. Adelman, had heard a presentation on this subject.

So on that level, if we believe Mr. Velikhov, the Soviet leadership has been briefed. How well this gets converted into policy in either nation is another question.

If I could just return to the question——

Senator **Proxmire**. Let me just interrupt. Was there any indication how the briefing was received by the leadership, any feedback, any indication?

Mr. **Sagan**. We do know that Foreign Minister Gromyko, in the presence of President Andreotti of Italy, did bring up the nuclear winter issue. So apparently it is on his mind. Beyond that, I have no information whatever.

On the question of whether to get down below threshold, it certainly seems to be the case that you could be below this very crude threshold for triggering nuclear winter and still have a very powerful and compelling nuclear deterrence. They are not incompatible.

It's possible to imagine a devastating retaliatory attack of one side on the other which nevertheless is small enough that it would not trigger nuclear winter.

Senator **Proxmire**. So it's possible to at least get on a much lower scale as far as counterforce and countervalue is concerned?

Mr. **Sagan**. That's right. The question is, if the arsenals were larger than what would trigger nuclear winter, could you restrain an exchange to be below the threshold? That seems to be a very serious question. My guess and many other people's is that once nuclear war breaks out, containing it is very difficult. That's why it seems so important to have the arsenals below threshold so that if war does break out at least nuclear winter wouldn't occur.

Senator **Proxmire**. Now I only have a couple more questions, you'd be happy to know, and I apologize for detaining you, but it's such a fascinating and critical subject, with such a superb panel, for as long as I have.

Admiral Gayler, it's been argued by Charles Zraket and others that a nuclear winter suggests it's not possible to build a command control and communications network for a protracted war involving a large number of nuclear weapons. In other words, it's not possible to do this over a period of weeks or months. Do you agree, and what are the implications of this conclusion to current U.S. policy?

Admiral **Gayler**. Well, I agree that in the presence of nuclear winter it's not possible to do that. I also believe in the presence of any major nuclear exchange it's not possible to sensibly fight a protracted nuclear war, for a lot of reasons, the first of which is, of course, that almost all command and control, however much we try to safeguard it, will have disappeared. So will most of the headquarters and the generals therein and the admirals at sea. So will most of the politicians, including this Congress and the President and his advisers in most common circumstances.

You will actually be up against a very tough constitutional question and that is whether the war can be conducted by somebody credibly in the constitutional line of succession, maybe the Assistant Secretary of Agriculture who happened to be vacationing in Maine, or a colonel in the Air Force who is airborne or out of the way by design or chance.

Senator **Proxmire**. Or even a Senator who's out in the States shaking hands when it happened.

Admiral **Gayler**. That could be. So I think it has no credibility. In fact, it is one of the three nuclear war fighting doctrines that I think we and the Soviets should formally give up. The doctrine of first use of nuclear weapons, of course, the Soviets have already indicated they would be happy to give up. The doctrine of counterforce that we've been discussing, and the doctrine of the protracted war. I think if we give up those doctrines they would be far more than paper declarations between us because we could go back to the kind of weapons, the deployment, the training, the doctrines of the military forces and everything else, all of which are highly observable. So it would be one of a number of steps that would reduce the probability of nuclear war that I think we ought to take. There are many steps besides and in addition to and supporting and synergistic with getting rid of nuclear weapons.

Senator Proxmire. Admiral, I've tried hard to find scientists who would come forward and disagree with this nuclear winter thesis. I did encounter one statement which I think I sent to every member of the panel by Mr. Cohen and he, unfortunately, couldn't be here, couldn't testify. We asked him to recommend somebody to represent his viewpoint and they couldn't be here either.

But their thesis is that nuclear winter would not occur in large part because our cities would be avoided. You gentlemen come down very hard on the other side on that.

But let me ask you, Admiral, is it possible to have a targeting policy that avoids cities, forests, and other high-fire areas and what targets would be left and what would be the military value of attacking them?

Admiral Gayler. When you ask if anything is possible, of course, generally speaking, unless there's some physical reason, the answer has got to be yes. Whether there could be any sensible policy of that kind from a military standpoint, I think not. You could conceivably target only silos that were out in the bush someplace, but if you do that effectively you would start killing people nonetheless. Or you could perhaps go after ships at sea, but that's a very dicey way to go after ships because of the problem of knowing where they are, particularly firing long-range weapons. Or you could possibly find an isolated military establishment that's pretty far from populations.

But generally speaking, I see no important class of military targets that are not in some way embedded in or upwind or in some way affecting populations.

Senator Proxmire. Finally, Mr. Sagan, several studies are underway attempting to verify or refine the nuclear winter study. Can you tell us what you know about these studies and whether they seem well coordinated and what you think the Federal Government ought to be studying at this time?

Mr. Sagan. Yes. There is, first of all, a study funded by the Defense Nuclear Agency performed by the National Academy of Sciences that has looked into this subject. Their report, I imagine, will be released sometime later this year. There is an interagency working group, at the assistant secretary-deputy administrator level, which was organized at the behest of the Director of the Office of Science and Technology Policy, Mr. Keyworth, which is talking about spending tens of millions of dollars for future studies, including experimental studies; for example, intentional burning, massive fires to follow the progress of the fire and the smoke.

There are a number of studies now underway at the National Weapons Laboratories, especially Livermore and Los Alamos. The Los Alamos study will be very sophisticated, including a three-dimensional general circulation model.

Beyond this, the Office of the Secretary of Defense has asked an organization with the best acronym in the business, CADRE—it stands, roughly, for the Center for Aerospace Doctrine Research—at Maxwell Air Force Base to deliver a report on the doctrinal implications of nuclear winter. It is, I understand, supposed to be available this summer.

There are increasing numbers of scientists who are working on the subject. It's clearly become a growth industry in the Department of Defense. Mr. Velikhov tells me that he has been given a 5 to 10 million ruble budget to do Soviet studies along the same line.

So I think at least we can be fairly confident that these studies will be pursued vigorously and at a high level.

The only concern that I have is that the work be done mainly in an unclassified context because of the obvious problem that if there is a classified conclusion that is different from the unclassified result and can't be discussed because it would reveal the classified information, then we are at an absurd standoff. However, there appears to be no present prospect of that.

My sense is that things are moving reasonably well, at least the scientific research. There are also, as you know, bills passed by both the House and the Senate mandating the Department of Defense to make a thorough study of the subject, including the policy and doctrinal implications and report back to the Congress by March of this coming year. If that bill survives the House-Senate conference committee—and I understand it is likely to do so—that will have a very important role as well in generating this information in a timely fashion.

Senator **Proxmire**. Well, gentlemen, thank you very much. This has been a superlative panel and you have certainly enlightened this Senator and the record will be made available to other members of the full committee and the Senate and I think you have served the country very well by your testimony this morning.

The subcommittee will meet tomorrow morning in room SD-138 with witnesses from the Defense Department and the Arms Control and Disarmament Agency.

[Whereupon, at 12:45 p.m., the subcommittee recessed, to reconvene at 10 a.m., Thursday, July 12, 1984.]

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THE CONSEQUENCES OF NUCLEAR WAR

THURSDAY, JULY 12, 1984

Congress of the United States, Subcommittee on International Trade, Finance, and Security Economics of the Joint Economic Committee,
Washington, DC.

The subcommittee met pursuant to recess, at 10 a.m., in room SD-138, Dirksen Senate Office Building, Hon. William Proxmire (vice chairman of the subcommittee) presiding.

Present: Senator Proxmire and Representative Mitchell.

Also present: Richard F. Kaufman, general counsel.

OPENING STATEMENT OF SENATOR PROXMIRE, VICE CHAIRMAN

Senator Proxmire. The subcommittee will come to order.

Yesterday, we heard testimony from four of the most eminent and respected persons in their fields, including Carl Sagan, one of the authors of the nuclear winter study. Regardless of one's views about the validity of the nuclear winter findings, it is clear that, in the years since the first atomic bombs were used, we have steadily learned more about the horrors of nuclear warfare. If anything, the destructive powers of nuclear explosions have been underestimated. The nuclear winter findings may be only the latest in a growing list of unpleasant surprises.

One of the shocking implications of nuclear winter is that we can destroy ourselves by attacking our enemy. Some experts have long maintained that there is no military usefulness to nuclear weapons, or to some types of nuclear weapons. Now we learn that, by employing the nuclear option, we may be shooting ourselves in the head. If the nuclear winter study is correct, we have thousands of weapons in our own arsenal that are pointed at ourselves. Of course, the same situation exists for the Soviet Union. The dilemma we face is that the strategic options we have adopted to assure deterrence could also assure our self-destruction.

We invited spokesmen for the Defense Department and the Arms Control Agency to address several kinds of questions related to the nuclear winter thesis. We asked the Defense Department to give us its views of the significance for policy of the latest findings about the effects of nuclear warfare. We asked the following specific questions: Does the possibility of a nuclear winter or what we already know about the effects of nuclear explosions require any change in our policies concerning nuclear weapons, stockpiles, strategic forces, and their potential use? What would be the budgetary consequences? Are the nuclear winter scenarios realistic in terms of megatonnage and targets?

We told the Arms Control Agency that we would like to know if it has considered whether arms control policy needs to be modified in light of the scientific evidence of what would happen to our society and others if a nuclear war occurred. For example, if the nuclear winter thesis were validated by the studies now in progress at the National Academy of Sciences and elsewhere, would it make any difference to current arms control policy?

Our witnesses are Mr. Richard L. Wagner, Assistant to the Secretary of Defense for Atomic Energy, accompanied by Mr. Franklin Miller, Directorate for Strategic Forces Policy, International Security Policy, Department of Defense; and Mr. David Emery, Deputy Director, U.S. Arms Control and Disarmament Agency, accompanied by Mr. Thomas Graham, Jr., General Counsel, ACDA.

Mr. Wagner, will you start off for us. Is this your slide device here?

Mr. **Wagner**. Yes, it is, Senator.

Senator **Proxmire**. Fine. If you would like to use that, go right ahead. I do hope, gentlemen, you can confine your remarks to a few minutes if possible so we can have questions.

STATEMENT OF RICHARD L. WAGNER, ASSISTANT TO THE SECRETARY OF DEFENSE FOR ATOMIC ENERGY, ACCOMPANIED BY FRANKLIN C. MILLER, DIRECTORATE FOR STRATEGIC FORCES POLICY, INTERNATIONAL SECURITY POLICY, DEPARTMENT OF DEFENSE

Mr. **Wagner**. Thank you, Senator. I am pleased to be here, in part because there has been an unfortunate perception on the part of some that the administration isn't paying attention to this matter or taking it seriously. I want to assure you at the very beginning that we are taking it seriously, both from the point of view of trying to understand the phenomena themselves better and also from the point of view of understanding the very questions you asked; what are the policy force structure, budgetary, and arms control implications. I hope that our work in both those areas will be made clear in both my short statement and in the subsequent questions.

Let me simply paraphrase then if I may the prepared statement I have.

U.S. policy is based upon the recognition, and has been for years, that a nuclear war would be one of the most terrible disasters that could befall mankind. The direct damage could cause the deaths or injury of millions, and the delayed effects of fallout and other serious long-term effects could lead to additional millions of casualties. It is clear that such a war would be catastrophic and the United States must continue to do everything we can to ensure that such a war never occurs.

During the last few years, new work has been done which raises additional issues about possible long-term consequences of nuclear war. What is new are the estimates of the long-term climatological effects of the smoke and soot produced by fires ignited by nuclear explosions. The defense community, in addition to the academic and nonacademic scientific community, has been conducting similar work. The Department of Energy laboratories have contributed materially, over decades actually, to this kind of work, and the Department of Defense as well. In fact, I should point out that much of the technology base that will be used and has been used to date to explore this particular effect, the nuclear winter effect, was in fact developed largely by the Department of Energy laboratories over the years to handle these kinds of large complicated problems. In particular, the DOD, in late 1982, through the Defense Nuclear Agency requested a study of this work to be done by the National Academy of Science. The original request was intended to look at the effects of dust in the atmosphere, but when a number of people, including people at the Department of Energy laboratories, began to identify this previously, frankly, overlooked effect of the smoke and soot, we did ask the National Academy to change their scope of their studies and look at that as well. That National Academy assessment has not yet been published but we expect it to be published this fall.

The first group, however, to actually publish a comprehensive paper was the group of Turco, Toon, Ackerman, Pollack, and Sagan. Their work and the work of others concludes that the smoke and soot produced by the fires could cause a temperature depression of tens of degrees that could last for months—a "nuclear winter." So far, the aggregate of the work of the technical community indicates that within a large range of uncertainty in their calculations—and I will come back to that point—there could indeed be a nuclear winter or there could be little effect from a wide range of possible scenarios.

Even if one takes an optimistic view that these effects would be at the lower end of the range of predictions, even such a small possibility of catastrophic effects has to be taken very seriously and we are studying the potential implications of this both for strategy and for our Strategic Modernization Program. We have an expanded program to understand these phenomena better, as I will describe later.

In addition to the technical work which is now being pulled together by the National Oceanic and Atmospheric Administration, we have in a number of ways begun to look at policy implications. Those of us here at the table have talked at length about the subject and others not represented here. We have the Defense Science Board undertaking to look both at the technical and at some of the connections between the policy and technical aspects. We have a number of contract studies underway. A group at the War College at Maxwell Air Force Base is taking a comprehensive look at the subject. So we have been looking at the policy implications.

So far, with the uncertainties and the wide range of possible outcomes of the examination of the technical questions, our view is that this phenomenon does not change the most fundamental aspects of our policy. It is our view that the highest confidence method to avoid the prospects of a nuclear winter and all the other terrible effects of a large nuclear exchange is to prevent war from ever occurring. That's the overriding objective of our defense policy. It has been ever since the 1940's at the beginning of the nuclear age, and our force structure and our R&D programs are devoted to that end.

I might note that the general directions that our modernization programs have taken and will continue to take and added to that perhaps considerations of the President's strategic defense initiative are such as to reduce, to some extent fortuitously but not entirely, the global effects of nuclear war even if deterrence were to fail.

Let me just amplify on that a moment by saying that during the last 20 years the number of nuclear weapons in our stockpile has declined by some 15 percent and the total yield in the stockpile has been reduced by about a factor of four. It's about one-fourth of what it was in the early 1960's.

Those evolutions have occurred for a number of reasons, but among them has been a continuing concern to reduce the kinds of damage that would occur if deterrence were ever to fail. In the early days global effects were considered to be fallout and so forth. But it has in fact been in the direction to reduce to some extent the possibility of the kinds of effects envisaged in a nuclear winter.

So at this time—and I don't want to say that this is the final conclusion—but at this time, all that I believe we can responsibly conclude about the most fundamental elements of policy is that defense strategy understands that a nuclear war can have no winner and must never be fought and has as its objective the credible deterrence of nuclear war at all levels. It is U.S. policy, and I believe that Mr. Emery will amplify on this, that a stable deterrent can be maintained on both sides. That policy is the basis of our proposals to the Soviet Union in negotiations for a START builddown. I believe that our objective of seeking deep reductions in nuclear weapons inventories on both sides must continue to be pursued and, if anything, that objective is reinforced by the possibility of severe climate effects that we are talking about this morning.

Further, our policy, the third and fundamental element of it, is that stable deterrence can best be maintained with modernized forces which incorporate, among other characteristics, improved survivability, safety, and command control features. I believe this objective is also unchanged by the broadest effects of the prospect of the nuclear winter.

It is essential that to preclude a nuclear winter we must preclude war, and to preclude a war we most continue to ensure that the U.S. deterrence is credible.

An additional point is that the President's strategic defense initiative, if it were in fact to lead to deployments—and today, the initiative consists of R&D programs to examine the possibilities—would complement the reductions proposals.

Defense technologies offer the possibility of intercepting warheads before they can kill people or start fires, providing further effective reduction in numbers of weapons, perhaps even below the levels likely to be negotiable in the near term.

Beyond these broad conclusions, with the current state of understanding and the current wide range of possibilities of the outcome of various scenarios—beyond that, as our understanding develops, we may well see other ways of reducing either the possibility or the severity of a nuclear winter phenomena if deterrence were to fail. These might involve changes in force characteristics, targeting which in turn could be reflected in budgets and so forth, but I am convinced personally that we really must understand the structure of the phenomena better, the sensitivities to the scenarios, and uncertainties in the technical parameters, before we can really responsibly address those more detailed aspects.

Several months ago then, because of our view that there could be these kinds of impacts, both the DOD and the Department of Energy began to expand our programs to understand these effects better. The program comprises research. It will be quite comprehensive on all aspects that we know of today on the effects of nuclear war on the global climate. I will not go on to describe the technical program, Senator, because I believe that's not your intent today. Let me simply point out that a few months ago, after we were a ways into planning the DOD and DOE programs, the administration directed that the National Oceanic and Atmospheric Administration develop a national research program to carry out essentially the same objectives that our own internal programs had seen. We strongly support this and are in the process of merging our ongoing work with the larger national program.

Let me at this point depart from my prepared statement to address briefly one of the particular questions you asked, which was the realism of the scenarios that have been used so far in these assessments, and let me address that by pointing out that it has been U.S. policy for many years to have force structures and targeting capabilities to be able to respond to an attack and therefore to deter that attack by prospective response in a number of different ways. By attacking the remaining Soviet strategic forces. On a broader basis, attacking the Soviet existing military capability, and the war production base, and by attacking leadership targets, and finally by attacking industrial and economic related targets.

We do have capability to do all those things. The proportions would vary from situation to situation. My point is that there is a wide range of possible scenarios that one would want to examine. If one adds to the wide range of possibilities in our own posture the fact that we simply do not know how the Soviets would use their forces—we have some views, but we don't know how they would use their forces—what that says is one has to examine a wide range of possible scenarios.

Within that wide range, I suspect that the number of scenarios that have been looked at are not unrepresentative. I think we will probably want to look at more rather than fewer scenarios as time goes on.

Furthermore, while it is both our policy and our strong belief that the technical aspects of these matters must be pursued unclassified, it may well be that the Department of Defense would want to examine on a classified basis some scenarios as our understanding of the technical matters matures.

Let me say that despite the fact that we are in fact putting together an extensive program to look at both the technical and the policy aspects, we don't expect the uncertainties in these matters will be reduced rapidly. The phenomena are very complex. A parallel to this might be the work that was done during the 1960's on fallout. It took about 5 years to assemble the data, the rather extensive data that existed on fallout, put it into a form which could be used repeatedly to examine a wide variety of scenarios, and the fallout problem is a cinch compared to this one.

So I suspect that we will not find a large reduction in the uncertainties and that it will take some years before we have gotten down to the point where we have reduced the uncertainties as much as it seems worthwhile to do.

Furthermore, there really may be a fundamental limit on how certain we can be because the nuclear winter phenomena themselves to the very extent that they are severe would perturb the fundamental characteristics and behavior of the atmosphere, which means that the only good reference we have for determining the validity of the climate models which is the current unperturbed behavior of the atmosphere, would be of limited value--not zero value, but limited value—in estimating the effects in question here.

So in common with many other nuclear weapons effects, the level of uncertainty itself will remain an important factor in considering the policy implications as we look at the finer details as they relate to force structure and targeting and so forth.

Finally, let me just conclude, Senator, by stressing again that while this new work has added another dimension to our perceptions of the consequences of nuclear war, it hasn't changed our fundamental tenets that such a war must be avoided and that that's the best way to avoid these kind of global effects, that deterrence is and must remain a cornerstone of our strategic policy, which means that our forces must be configured in such a way that the Soviet planners remain uncertain about their capability to achieve military objectives in some kind of a crisis.

The President's modernization program, arms reductions proposals, and perhaps in the future the strategic defense initiative are all efforts to achieve that goal, while at the same time minimizing the effects of nuclear war.

Thank you, Senator. That concludes my statement.

[The prepared statement of Mr. Wagner follows:]

PREPARED STATEMENT OF RICHARD L. WAGNER

U.S. POLICY IS BASED UPON THE RECOGNITION THAT A NUCLEAR WAR WOULD BE ONE OF THE MOST TERRIBLE DISASTERS THAT COULD BEFALL MANKIND. THE DIRECT DAMAGE FROM BLAST, HEAT AND NUCLEAR RADIATION COULD CAUSE THE DEATHS OR INJURY OF MILLIONS; THE DELAYED EFFECTS OF NUCLEAR FALLOUT COULD LEAD TO ADDITIONAL MILLIONS OF CASUALTIES. IT IS CLEAR THAT SUCH A WAR WOULD BE CATASTROPHIC AND THE UNITED STATES MUST CONTINUE TO DO EVERYTHING IN ITS POWER TO INSURE THAT SUCH A WAR NEVER OCCURS.

DURING THE LAST FEW YEARS, NEW WORK HAS BEEN DONE WHICH RAISES ADDITIONAL ISSUES ABOUT POSSIBLE LONG TERM CONSEQUENCES OF NUCLEAR WAR. WHAT IS NEW ARE THE ESTIMATES OF THE LONG TERM CLIMATOLOGICAL EFFECTS OF THE SMOKE AND SOOT PRODUCED BY FIRES IGNITED BY NUCLEAR EXPLOSIONS. THE DEFENSE COMMUNITY HAS BEEN CONDUCTING SIMILAR WORK--THE DOE LABORATORIES HAVE CONTRIBUTED MATERIALLY, AND IN LATE 1982 THE DOD, THRU THE DEFENSE NUCLEAR AGENCY, REQUESTED A STUDY OF THIS WORK TO BE DONE BY THE NATIONAL ACADEMY OF SCIENCE--BUT THE FIRST GROUP TO CONCLUDE THAT THESE EFFECTS WERE SUFFICIENTLY UNDERSTOOD TO BE PUBLISHED AND PUBLICIZED WERE THE AUTHORS TURCO, TOON, ACKERMAN, POLLACK AND SAGAN. THEIR WORK CONCLUDES THAT THE SMOKE AND SOOT

PRODUCED BY THE FIRES COULD CAUSE A TEMPERATURE DEPRESSION OF TENS OF DEGREES THAT COULD LAST FOR MONTHS--A "NUCLEAR WINTER". SO FAR, THE AGGREGATE OF THE WORK OF THE TECHNICAL COMMUNITY--WHICH HAS COVERED A WIDE BUT NOT COMPLETE RANGE OF THE MANY PARAMETERS INVOLVED--INDICATES THAT, WITHIN THE LARGE RANGE OF UNCERTAINTY OF THEIR CALCULATIONS, THERE COULD INDEED BE A "NUCLEAR WINTER" OR THERE COULD BE LITTLE EFFECT.

HOWEVER, EVEN A SMALL POSSIBILITY OF SUCH CATASTROPHIC EFFECTS MUST BE CONSIDERED VERY SERIOUSLY, AND THE ADMINISTRATION IS STUDYING THE POTENTIAL IMPLICATIONS OF THIS NEW FACET OF NUCLEAR WAR, BOTH FOR OUR STRATEGY OF DETERRENCE AND FOR OUR STRATEGIC MODERNIZATION PROGRAM. SO THE ADMINISTRATION HAS STARTED AN EXPANDED PROGRAM TO UNDERSTAND THESE PHENOMENA BETTER, AS WILL BE DESCRIBED LATER. IT IS IMPORTANT TO UNDERSTAND THAT THE UNCERTAINTIES RELATING TO THE GLOBAL EFFECTS RESIDE IN TWO BROAD CATEGORIES, THE SCIENTIFIC AND TECHNICAL UNCERTAINTIES OF THE PHENOMENON ITSELF, WHICH ARE LARGE, AND THE VARIATIONS AMONG SCENARIOS, WHICH CAN BE SELECTED FOR ANALYSIS BUT WHICH CANNOT BE PREDICTED, WITH ANY CONFIDENCE, IN ADVANCE. IT IS DIFFICULT TO ASSESS POLICY IMPLICATIONS IN DETAIL WHEN THERE ARE SUCH LARGE UNCERTAINTIES.

ONE THING IS CLEAR TO ME; THE HIGHEST CONFIDENCE METHOD TO AVOID THE PROSPECTS OF A "NUCLEAR WINTER"--AND ALL OF THE OTHER

TERRIBLE EFFECTS--IS TO PREVENT WAR FROM EVER OCCURRING. THAT IS THE OVERRIDING OBJECTIVE OF OUR DEFENSE POLICY, OUR FORCE STRUCTURE, AND OUR RESEARCH AND DEVELOPMENT PROGRAMS. IT IS WORTH NOTING THAT THE GENERAL DIRECTIONS OUR MODERNIZATION PROGRAMS HAVE TAKEN AND WILL CONTINUE TO TAKE ALONG WITH THE PRESIDENTS STRATEGIC DEFENSE INITIATIVE, ARE SUCH AS TO REDUCE--PERHAPS FORTUITOUSLY--THE GLOBAL EFFECTS OF A NUCLEAR WAR EVEN IF DETERRENCE WERE TO FAIL.

I BELIEVE, THEN, THAT AT THIS TIME ALL WE CAN RESPONSIBLY CONCLUDE IS AS FOLLOWS:

1) OUR DEFENSE STRATEGY, IN RECOGNITION THAT A NUCLEAR WAR CAN HAVE NO WINNER AND MUST NEVER BE FOUGHT, HAS AS ITS OBJECTIVE THE CREDIBLE DETERRENCE OF NUCLEAR WAR AT ALL LEVELS. I BELIEVE THAT PREVENTION OF NUCLEAR WAR MUST REMAIN THE PRINCIPAL OBJECTIVE OF OUR STRATEGY AND THAT THE EFFECTS OF NUCLEAR WAR ON THE GLOBAL CLIMATE DO NOT ALTER THAT OBJECTIVE.

2) IT IS U.S. POLICY THAT A STABLE DETERRENT CAN BE MAINTAINED WITH SUBSTANTIALLY REDUCED NUMBERS OF NUCLEAR WEAPONS ON BOTH SIDES. THAT POLICY IS THE BASIS OF OUR PROPOSALS TO THE SOVIET UNION IN NEGOTIATIONS FOR A START BUILDDOWN. I BELIEVE THAT OUR OBJECTIVE OF SEEKING DEEP

REDUCTIONS IN THE NUCLEAR WEAPONS INVENTORIES OF BOTH THE UNITED STATES AND THE SOVIET UNION MUST CONTINUE TO BE PURSUED--IF ANYTHING, THAT OBJECTIVE IS REINFORCED BY THE POSSIBILITY OF SEVERE CLIMATE EFFECTS.

3) OUR POLICY FURTHER HOLDS THAT STABLE DETERRENCE CAN BEST BE MAINTAINED WITH MODERNIZED FORCES WHICH INCORPORATE, AMONG OTHER CHARACTERISTICS, IMPROVED SURVIVABILITY, SAFETY, AND COMMAND CONTROL FEATURES. I BELIEVE THAT THIS OBJECTIVE REMAINS VALID. IT IS ESSENTIAL THAT WE CONTINUE TO MODERNIZE OUR NUCLEAR FORCES TO ENSURE THAT THE US DETERRENT IS INDEED CREDIBLE.

BEYOND THIS, AS OUR UNDERSTANDING DEVELOPS, WE MAY SEE OTHER WAYS OF REDUCING THE POSSIBILITY OR SEVERITY OF THE "NUCLEAR WINTER" PHENOMENA IF DETERRENCE WERE TO FAIL.

BECAUSE OF THE IMPORTANCE OF THESE MATTERS, SEVERAL MONTHS AGO THE DOD AND THE DOE BEGAN TO EXPAND OUR PROGRAMS TO UNDERSTAND THESE EFFECTS BETTER. THE PROGRAM COMPRISES RESEARCH ON ALL ASPECTS OF THE EFFECTS OF NUCLEAR WAR ON THE GLOBAL CLIMATE. WE ARE PLACING LARGEST EMPHASIS ON THOSE THINGS THAT ARE MOST UNCERTAIN: UNDERSTANDING THE INITIATION OF MASSIVE FIRES, THE FORMATION OF SMOKE PLUMES, THE PHYSICS AND CHEMISTRY OF ATOMOSPHERIC PARTICULATES, THE MOTION AND BEHAVIOR OF SMOKE

CLOUDS, AND MODELING OF THE BEHAVIOR OF THIS MATERIAL IN GLOBAL ATMOSPHERIC CIRCULATION. TWO AND THREE DIMENSIONAL WEATHER MODELS ARE BEING RUN, USING STATE-OF-THE-ART MODELING OF THE PHYSICS, TO PROVIDE THE BEST POSSIBLE ESTIMATES OF THE CLIMATOLOGICAL CHANGES. PREVIOUS MAJOR FIRES ARE BEING ANALYZED TO PROVIDE DATA ON FIRE SPREAD, PARTICULATE LOFTING AND THE MIXING AND DIFFUSION OF SMOKE IN THE ATMOSPHERE. EVEN VOLCANIC ERUPTIONS ARE BEING STUDIED TO PROVIDE INSIGHT INTO THE ATMOSPHERIC MIXING AND DIFFUSION PROCESSESS. IN ADDITION, WE ARE AUGMENTING OUR RESEARCH INTO THE BIOLOGICAL CONSEQUENCES OF PROLONGED TEMPERATURE DEPRESSIONS, REDUCED SUNLIGHT AND THE RADIOLOGICAL ENVIRONMENT. WHILE THIS IS A VERY DIFFICULT AREA, IT IS ESSENTIAL IN ORDER TO GUIDE THE RESEARCH IN CLIMATIC EFFECTS. OUR OBJECTIVE IS TO PROVIDE AN ADEQUATE UNDERSTANDING OF THE TECHNICAL ISSUES FOR THE NATIONAL DECISION MAKERS, AND TO PUT THE GLOBAL CLIMATOLOGICAL EFFECTS IN CONTEXT WITH THE OTHER LONG TERM EFFECTS OF NUCLEAR WAR. THE RESEARCH PROGRAM IS BEING CONDUCTED IN BOTH PRIVATE AND ACADEMIC INSTITUTIONS AS WELL AS THE NATIONAL LABORATORIES.

TO BROADEN THE RESEARCH BASE, AND ENSURE A BROADER PERSPECTIVE, THE ADMINISTRATION HAS DIRECTED THAT THE NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION DEVELOP A NATIONAL RESEARCH PROGRAM WITH THE OBJECTIVE OF OBTAINING A BETTER UNDERSTANDING OF THE EFFECTS OF NUCLEAR WAR UPON THE GLOBAL CLIMATE AND WHERE

POSSIBLE TO REDUCE THE UNCERTAINTIES ASSOCIATED WITH THESE PHENOMENA. THE DEPARTMENT OF DEFENSE STRONGLY SUPPORTS THIS NATIONAL RESEARCH PROGRAM AND IS PREPARED TO MERGE ITS ONGOING SCIENTIFIC RESEARCH EFFORTS WITH THE LARGER NATIONAL PROGRAM.

HOWEVER, IN ALL CANDOR, WE DO NOT EXPECT THAT THE UNCERTAINTIES RELATED TO GLOBAL EFFECTS WILL BE REDUCED RAPIDLY, CONSIDERING THE COMPLEXITY OF THE SUBJECT AND THE PAUCITY OF DATA ON THE PHYSICS AND CHEMISTRY INVOLVED IN THE PHENOMENON. FURTHERMORE, THERE MAY BE A FUNDAMENTAL LIMIT TO HOW CERTAIN WE CAN BE OF THE CLIMATE EFFECTS, BECAUSE THE "NUCLEAR WINTER" PHENOMENA THEMSELVES, TO THE EXTENT THAT THEY WERE TO BE SEVERE, WOULD RESULT IN MAJOR CHANGES IN THE CHARACTERISTICS AND BEHAVIOR OF THE ATMOSPHERE. THIS MEANS THAT THE ONLY GOOD REFERENCE WE HAVE FOR DETERMINING THE VALIDITY OF OUR CLIMATE MODELS- THE CURRENT, UNPERTURBED, ATMOSPHERIC CIRCULATION--WOULD BE OF LIMITED VALUE IN ESTIMATING THE EFFECTS IN QUESTION. THUS, IN COMMON WITH MANY OTHER NUCLEAR WEAPONS EFFECTS, THE LEVEL OF UNCERTAINTY ITSELF WILL BE AN IMPORTANT FACTOR IN THE CONSIDERATION OF POLICY IMPLICATIONS.

SINCE THE LEVEL OF UNCERTAINTY IS ITSELF A MAJOR FACTOR IN THINKING ABOUT THE POLICY AND FORCE STRUCTURE IMPLICATIONS, AND WHILE WE WILL CONTINUE TO THINK ABOUT THESE IMPLICATIONS IN PARALLEL WITH THE TECHNICAL WORK, IT WOULD BE IMPRUDENT NOW TO

CHANGE OUR POLICIES OR FORCE STRUCTURE UNTIL THE TECHNICAL MATTERS ARE BETTER UNDERSTOOD.

IN CLOSING, LET ME STRESS THAT WHILE THIS NEW WORK HAS ADDED YET ANOTHER DIMENSION TO OUR PERCEPTIONS OF THE CONSEQUENCES OF NUCLEAR WAR, IT HAS NOT CHANGED THE FUNDAMENTAL TENET THAT SUCH A WAR MUST BE AVOIDED. DETERRENCE IS--AND MUST REMAIN--THE CORNERSTONE OF OUR STRATEGIC POLICY. OUR FORCES MUST BE CONFIGURED IN SUCH A WAY THAT THE SOVIET PLANNERS REMAIN UNCERTAIN ABOUT THEIR CAPABILITY TO ACHIEVE THEIR MILITARY OBJECTIVES. THE PRESIDENT'S STRATEGIC MODERNIZATION PROGRAM, ARMS REDUCTION PROPOSALS, AND THE STRATEGIC DEFENSE INITIATIVE ARE ALL EFFORTS TO ACHIEVE THAT GOAL WHILE AT THE SAME TIME MINIMIZING THE EFFECTS OF NUCLEAR WAR, INCLUDING THE POSSIBLE GLOBAL EFFECTS.

THIS CONCLUDES MY PREPARED REMARKS. I APPRECIATE THE OPPORTUNITY TO DISCUSS THIS VITALLY IMPORTANT SUBJECT WITH YOU. I WOULD BE HAPPY TO ANSWER ANY QUESTIONS THAT YOU MIGHT HAVE.

Senator **Proxmire**. Thank you, Mr. Wagner.
Mr. Emery.

STATEMENT OF DAVID F. EMERY, DEPUTY DIRECTOR, U.S. ARMS CONTROL AND DISARMAMENT AGENCY, ACCOMPANIED BY THOMAS GRAHAM, JR., GENERAL COUNSEL

Mr. **Emery**. Thank you very much, Senator. We very much appreciate the opportunity to address this subject today and we think that this is a very important matter in the Arms Control and Disarmament Agency. In fact, all pertinent agencies of the U.S. Government need to pay particularly close attention to this issue.

Ever since the first nuclear weapons were detonated over Hiroshima and Nagasaki the terrible consequences of the use of nuclear weapons have been recognized by all mankind and it has been the policy of every U.S. President since that the first and highest national defense priority of the United States is to prevent the outbreak of nuclear war. Even before the discovery of the phenomenon known as the nuclear winter the consequences of fighting a nuclear war were known to be absolutely unacceptable. This view was reaffirmed by the President in his address to the U.N. General Assembly when he said: "A nuclear war cannot be won and must never be fought." It is, therefore, the policy of this administration, like every post-war administration before it, to maintain a policy of deterring the Soviet Union from initiating warfare, and the primary instrument for doing this is to maintain a credible deterrent. This is why our Strategic Modernization Program is so important and essential. Equally important are the administration's efforts to reduce the likelihood of a nuclear war by negotiating equitable and verifiable nuclear arms control agreements that provide for significant reductions in the nuclear arsenals of both sides to equal and more stable levels.

Recently, much attention has been drawn to a possible consequence of nuclear war—so-called nuclear winter—which some scientists believe could produce a significant cooling of the Earth's surface and prolonged periods of darkness. The nuclear winter is quite possibly another phenomenon to be added to the list of catastrophies which the human race would have to suffer as the result of a nuclear war. While many scientists who have examined this phenomenon are convinced that it would occur, there is widespread disagreement about its magnitude, duration, and the size of attack which could trigger it. Because the discovery of this phenomenon is so recent, and the uncertainties so large, we cannot yet draw final conclusions about the policy implications this phenomenon could have.

The administration is committed to a program to try to reduce these technical uncertainties and ACDA will participate in this program. However, the important point that is reinforced by this debate is the absolute necessity to avoid such a war. The United States adopted a policy of deterrence as early as 1946 and this policy has been upheld by every administration since that time. Deterrence serves our national interest and that of our allies, both by deterring any other country from initiating a war and by assuring that our vital interests will be protected. Currently we are seeking to strengthen deterrence by modernizing our strategic nuclear forces so that their retaliatory capability is credible in the minds of our adversary. We are also seeking to strengthen deterrence through arms control by proposals which would significantly reduce the nuclear arsenals on both sides and create a more stable and balanced strategic relationship between ourselves and the Soviet Union. Unfortunately, however, the Soviet Union has suspended the nuclear arms negotiations and is continuing its unwillingness to negotiate a more stable nuclear arms environment.

There are those who argue that our ultimate goal should be the elimination of nuclear weapons. This is certainly the long-term goal of the President to make nuclear weapons obsolete. However, in the interim, until such a goal can be reached, we have no choice than to pursue the course we have chosen: to maintain a credible nuclear deterrent and to attempt to negotiate reductions in nuclear weapons that would contribute to enhancing stability and reducing the risk of war.

Senator **Proxmire**. Thank you very much, Mr. Emery.

We are going to follow a 10-minute rule, if that's all right with Congressman Mitchell.

Mr. Wagner, Secretary Weinberger said in his posture statement for fiscal year 1983 that: "It is our policy to impose termination of a major war on terms favorable to the United States and its allies, even if nuclear weapons have been used."

Now both you and Mr. Emery this morning have referred to President Reagan's State of the Union Message in which he said: "A nuclear war could never be won and should never be fought."

Do you see a contradiction here? I do. It seems to me that if the President is right, we're changing the policy that was announced in the posture statement by Secretary Weinberger in 1983, or are we?

Mr. **Wagner**. Senator, I don't think so. I don't think there's a contradiction between those two policies.

Senator **Proxmire**. Let me just make my question clearer then. What the posture statement said is that it is our policy to impose termination of a major war on terms favorable to the United States and its allies even if nuclear weapons have been used. Now you say that we could terminate a nuclear war on favorable terms to ourselves, is that correct?

Mr. **Wagner**. Senator, both statements address deterrence. It may not appear on the surface that Secretary Weinberger's statement addresses deterrence, but in fact it does.

Senator **Proxmire**. I call your attention to the fact that Secretary Weinberger said: "even if nuclear weapons have been used," not if they are——

Mr. **Wagner**. Let me finish the thought if I may, sir. Deterrence involves addressing yourself to what the plans, and thoughts, and ideas of the potential adversary are—the Soviets in this case. We have believed for years that the Soviets do not see the problem of nuclear war and nuclear weapons in the same way we do, that they don't think in terms of deterrence; that they do in fact think in terms of war fighting. We must therefore address, in order for our deterrence to be effective, their mindset on the problem.

Therefore, we have to project the prospect to them that in their own terms, if a war were fought, it could be terminated on terms not favorable to them. That is the intent behind those kinds of statements.

Senator **Proxmire**. Well, Secretary Weinberger did not say "not favorable to them." It's my view that they wouldn't be favorable to anybody. If we fought a nuclear war the results would be, as the President indicated, nobody would win. But this statement by Secretary Weinberger indicates it could be terminated on terms favorable to ourselves even if nuclear weapons have been used.

Mr. **Wagner**. Well, the purpose of his statement was to cover the possibility that the Soviets might not have the same view that you, and I, and Secretary Weinberger, and the President have of the impossibility of fighting and winning a nuclear war. If they don't have that same view, then one has to pose the prospect for them that our forces have the capability of achieving an end that they would not like to see achieved.

Senator **Proxmire**. Well, was this then a statement directed to Russia or was it directed to our citizens too?

Mr. **Wagner**. Everything that public officials say regarding matters of deterrence have to take account how they will be viewed in the Soviet Union it seems to me.

Senator **Proxmire**. Well, it's very hard for me to understand a statement that indicates that we could use nuclear weapons and still terminate the war on terms favorable to ourselves, but I appreciate your response.

Now, Mr. Wagner, just to keep the record straight, you said there would be millions of deaths from the direct effects of a nuclear war and the delayed effects from fallout would lead to additional millions of casualties.

Isn't it true that estimates of deaths from the immediate effects of nuclear war if cities are targeted range from several hundred million to 1.1 billion people, as estimated by the World Health Organization, and that an additional 1.1 billion could die from delayed effects, about half the people in the world?

Mr. **Wagner**. Yes, sir, I've seen those kinds of estimates. I've seen lower estimates. There's a very wide range of estimates. The effects are very uncertain. Even before the nuclear winter phenomenon was identified, the effects of fallout or even the effects of the direct phenomenon ——

Senator **Proxmire**. Then you stand by the notion that it would not be hundreds of millions?

Mr. **Wagner**. Oh, it might well be hundreds of millions.

Senator **Proxmire**. You say you don't know? It could be millions, or it could be hundreds of millions, or——

Mr. **Wagner**. By saying millions, I didn't mean a few million. I meant millions as opposed to thousands. Of course, perhaps hundreds of millions perhaps at the highest level.

Mr. **Miller**. The category of millions, sir, means that the event would be catastrophic, regardless of whether it's a 100 million, or 200 million, or 500 million.

Senator **Proxmire**. Does the Defense Department have its own estimates of the numbers that would die in a nuclear war or do you just say that lots of people would die and we have no idea?

Mr. **Miller**. As Mr. Wagner indicated, there is a wide range of possible scenarios. There is no one idea.

Senator **Proxmire**. Well, can you give us the range? Would it be—can you conceive of a nuclear war involving the United States and the Soviet Union that would result in 50 million or 100 million?

Mr. **Wagner**. Of course.

Senator **Proxmire**. That low? Is that all on both sides?

Mr. **Wagner**. Possibly, yes.

Senator **Proxmire**. Give us a little bit of detail on how that war might develop in your view with the United States and the Soviet Union both involved.

Mr. **Wagner**. If it were in fact a limited war in which our efforts to structure our forces to be able to control escalation were successful, then I could imagine a termination at some level where the fatalities might be tens or hundreds of millions. I can also imagine—these things are very hard to say.

Senator **Proxmire**. Of course they are, and I don't mean to be difficult for you, but it just seems to me that if we have a war with the Soviet Union, it would be very, very hard to terminate that war without an absolutely catastrophic destruction on both sides involving most of our population and most of their population. It's just very hard for me to imagine a scenario in which there would be a termination after let's say one or two cities have been hit or one or two military targets had been hit. One side or the other is going to feel that they have to pursue it.

Mr. **Wagner**. Perhaps; but as long as we're imagining, you could perhaps imagine that the initial destruction would be catastrophic, that both sides would stop, and who can say? I think, Senator, the point is, the effects would be catastrophic, and whether the term "catastrophic" implies hundreds of millions or a billion seems to me to be an exercise in semantics.

Senator **Proxmire**. Well, has the Defense Department done studies or made estimates of the damages that would be done to the U.S. economy and the number of deaths that would be caused by a protracted nuclear war and can you give us those estimates?

Mr. **Wagner**. I am not aware of such studies. I suspect that the Department has looked at the studies, including some of the ones that you quote, within the wide range of uncertainties and the variations in scenario. It seems not particularly fruitful to be looking for the finetuning of the estimates.

Senator **Proxmire**. Well, have you made estimates of the various scenarios and the number of warheads that would be used in a nuclear war, including protracted nuclear war? Can you give us those figures?

Mr. **Wagner**. I cannot. We certainly look at a number of scenarios and they encompass a wide range of possibilities and I can't discuss the scenarios further because most of that work tends to be classified.

Senator **Proxmire**. Well, I understand the importance of classification, but it would seem to me that in a case like this, which is so absolutely critical for our people and for people throughout the world to understand it, the Defense Department which has billions of dollars to conduct research of all kinds would be able to make some estimates that would be quite reliable on what would happen in the event of a protracted nuclear war. You have no figures on that?

Mr. **Wagner**. Senator, I think the figures like that do exist. When a particular scenario is looked at, I'm certain that one looks at the fatalities involved. The purpose of looking at those things and trying to understand the sensitivities is to see whether there are perhaps gaps in our deterrent capability, and that's what those scenarios are generally structured for.

Mr. **Miller**. Senator, if I might, you used the term "protracted nuclear war." That term does not have any specific meaning to us. There is no scenario that says protracted nuclear war that goes on for *x* number of months.

Senator **Proxmire**. Well, use your own adjective. You can modify it any way you want. I'm just trying to distinguish if from what Mr. Wagner indicated earlier. You might have one exchange and that would be it. Protracted nuclear war presumably would last for several weeks at least, perhaps for months, and it would obviously, under those circumstances, involve many nuclear weapons.

Mr. **Miller**. Yes, sir; it could. It could involve a few nuclear weapons. It could involve thousands of nuclear weapons.

Senator **Proxmire**. A protracted war wouldn't involve two nuclear weapons.

Mr. **Miller**. I said a few, but it is impossible to predict what a nuclear war would be like and, as a result, and in recognition of the fact that the casualties as a result of large nuclear exchanges would be horrific on both sides, our policy of the Department remains to deter that. Regardless of the number of weapons used, the casualties would be horrific and, as a result, the policy of the Department remains to deter aggression at every level, including every possible level of nuclear aggression.

Senator **Proxmire**. If Congressman Mitchell would permit me, I would just like to point out that it's one thing to say the casualties would be horrific and they would be terrible, but it seems to me that we would have more intelligent and thoughtful and effective policies, recognizing the very great difficulty of doing this, if we had some notion of what the dimensions would be under various scenarios.

As I pointed out in my opening statement, the nuclear winter thesis suggests, among other things, that you shoot yourself in the head if you get into a war even if the other side doesn't respond because of the global catastrophe in which you create the worst environmental disaster, as Mr. Sagan has pointed out, in 50 million years, which could by itself exterminate the human race.

Mr. **Miller**. If I could respond briefly to that one point, the main point of our strategy is a deterrent one, to prevent the Soviets from launching an attack of whatever size. The key variable would be the size and nature of the Soviet aggression in the first place. As Mr. Wagner pointed out in the very beginning, that is impossible to determine with any certainty.

Mr. **Wagner**. Could I add to that, Senator?

Senator **Proxmire**. Certainly.

Mr. **Wagner**. We do not deter by prospect of fatalities or certainly not prospect of fatalities alone. It has been our view for many years that given what we can see about the Soviet view of this matter—and I'm not trying to say that the Soviets aren't concerned about the fatalities of nuclear war—what I'm saying is they have structured their forces in a way that indicates that their view of the interaction, the nuclear interaction, has to do with force on force, military versus military interactions. Perhaps they think that is what would deter us best. Who knows?

Therefore, our measures of deterrence have to do more with reducing the capability of the Soviet Union to achieve possible war objectives than with assessing some number of fatalities.

Senator **Proxmire**. My time is up. I have imposed on Congressman Mitchell too long. Go right ahead.

Representative **Mitchell**. It's no imposition at all. I wanted to dig even deeper in that line.

Mr. Emery, it's good to see you again.

Mr. **Emery**. Thank you very much. I hope your questions will end before the ball game tonight. Are you going, too?

Senator **Proxmire**. A double header at 5 o'clock.

Representative **Mitchell**. I'm not at all sure that it will conclude that rapidly.

How many nuclear weapons do we have in the world?

Mr. **Emery**. There are a variety of estimates. As far as the classified data is concerned, I would be very happy to give you information in a closed session.

Mr. **Wagner**. I think the numbers are classified.

Representative **Mitchell**. Is 50,000 in the ballpark?

Mr. **Wagner**. The unclassified phrase we've been using is a few tens of thousands?

Representative **Mitchell**. A few tens of thousands.

Mr. **Wagner**. I'm sorry if that sounds evasive, but the numbers are classified as to 40 to 50 or 60.

Representative **Mitchell**. You see, you add to the confusion in the minds of the American public when they see figures ranging from 20,000 nuclear weapons to 50,000 nuclear weapons. People are confused. Well, you're saying a few tens of thousands.

OK. Let's take 20,000. With, let's say, one-third of that 20,000 being utilized in a nuclear war, what might possibly be the impact in terms of deaths, destruction, and so forth?

Mr. **Wagner**. Hundreds of millions, perhaps as high as the highest estimates that Senator Proxmire referred to.

Representative **Mitchell**. That's using one-third of our present capacity.

Mr. **Wagner**. Or perhaps all of it.

Representative **Mitchell**. Well, I'm saying one-third of the 20,000. Again, I will ask the whole panel, if you have that capacity using one-third of the weapons now in place, do you need more?

Mr. **Wagner**. We don't need more. We do need a modernized capability.

Representative **Mitchell**. I'm coming to that next.

Mr. **Wagner**. Let me address this question of numbers because there is a factor that bears on the number issue. It is our policy in order to deter attack to be able to pose a prospect in the Soviets' mind that we can sustain a large attack and still have enough weapons left to be able to respond in a way that would be unacceptable to them. That means that we must be able to respond in a case where a large fraction of our initial number of weapons has been destroyed by the Soviet attack. That adds a multiplier to the arithmetic.

Another factor that enters is that not all of our forces that are on alert are deployed in a way which can respond.

Representative **MITCHELL**. Let me tell you what I'm trying to do. I'm just a guy who lives on Madison Avenue in Baltimore. I'm not a great expert. I'd just like to raise some questions as to whether or not one-third of 20,000 nuclear weapons now in place would have the impact that is of such horrendous dimensions that maybe it would disturb the world for 10 or 20 or 30 years, and you have agreed to that.

Now remember, this is just a little guy living there in Baltimore and doesn't know all this stuff. Why are you modernizing? Does that mean you can kill more quickly?

Mr. **WAGNER**. No, sir. The intention is not to kill people. It is to deter a Soviet attack. The reason for modernizing is because over the last decade or so, over the decade of the seventies I should say, our forces aged. The Soviets in fact carried out a modernization program. I'm not saying we did nothing. However, by the end of that decade a situation had developed in which in some circumstances—and one should be very conservative about insuring deterrence—in some circumstances, our deterrents might have been vulnerable to attack so that not enough would have been left to pose a credible response to the Soviets. That's why we need to modernize it.

Representative **MITCHELL**. Take it slowly for me and help me develop this. When you say modernize, could you give me one simple, clear-cut illustration of modernization?

Mr. **WAGNER**. I'm sorry about the jargon. We're talking about Trident submarine systems, the air launch cruise missile, other things not related to numbers of weapons, ensuring more invulnerable command control.

Representative **MITCHELL**. I'm kind of familiar with some of those. Would not the bottom line of that modernization be, in the event of a nuclear war, to dispatch weapons more quickly than you could at the present time?

Mr. **WAGNER**. More quickly? No, sir.

Representative **MITCHELL**. Greater kill?

Mr. **WAGNER**. No, sir.

Representative **MITCHELL**. Just to show them we can do something?

Mr. **WAGNER**. No, sir. It is to be able to survive a massive Soviet attack with higher certainty than we were able to.

Representative **MITCHELL**. What do you mean?

Mr. **WAGNER**. All of those weapons systems—Trident, B-1, the air launch cruise missile—have characteristics that make it more difficult for the Soviets to destroy our deterring retaliatory capability. The Trident submarine, for instance, is quieter in the water and less susceptible therefore to being found and attacked and destroyed by the Soviet Union. The B-1 bomber can escape from its base under attack faster and therefore more will survive and therefore the prospect of being able to destroy it is not there for the Soviets.

Representative **Mitchell.** Those which are left, those which are not destroyed, don't you want to use them?

Mr. **Wagner.** The next step in the argument then is—we don't intend to use those to target for civilian fatalities because it has been our view since I think the late 1960's that posing only that kind of response would not be credible in the Soviet eyes as a response.

Representative **Mitchell.** You can't even adduce the argument there with any kind of logic saying that it's not targeted to civilians. That is almost a specious argument. If the impact of the nuclear war, if indeed a nuclear war takes place, the civilians can be moved 50,000 miles from there and they're still going to suffer. Targeting is a specious argument to raise just about targeting it just for civilians.

Mr. **Wagner.** Congressman Mitchell, I——

Representative **Mitchell.** I'm sorry. Go ahead.

Mr. **Wagner.** You have your finger on—and in fact, Senator Proxmire in his opening statement used the word "dilemma"—"The dilemma we face is that the strategic options we have adopted to assure deterrence could also assure our self-destruction." That's not a new dilemma.

Our point is that the way to avoid those kinds of catastrophic consequences is not to have a war to begin with. We are attempting to achieve that end in two ways. One is by maintaining a deterrent which is secure enough that the Soviets in some unimaginable political crisis would not feel that that was the best of the bad lot of possibilities, to attack that deterrent. The other way is through the arms control.

Representative **Mitchell.** May I have a little more insight? You were talking about the best-case scenario. I'm talking about the worst-case scenario where a war breaks loose and all that we've stockpiled, all that we have on hand, would be used for destruction, wouldn't it? They've already hit us and we're going to hit back, right?

Mr. **Wagner.** It would produce millions of fatalities, there's no question about that, even if we did not target civilians.

Representative **Mitchell.** So the deterring factor becomes a destruction factor, right? That's the simplest way to put it. Is that correct?

Mr. **Miller.** Of a wide variety of things which are valuable to the Soviets.

Representative **Mitchell.** The answer is yes, right?

Mr. **Wagner.** That is the essence of deterrence, is to threaten unacceptable consequences.

Representative **Mitchell.** I'm saying deterrence fails, somebody goes beserk.

Mr. **Wagner.** That has been a dilemma since——

Representative **Mitchell.** What we have left is to be used for the destruction of those who went against us and it would be our own destruction because that's what it would be.

Mr. **Wagner.** At the risk of further complicating this—and it is a complicated subject—let me ask—perhaps it's not fair to ask you a question, sir, but would it be better then for us to structure our forces to be much more accurate so that we could attack Soviet military targets without producing civilian casualties?

Representative MITCHELL. Of course not. The approach would be a sincere, dedicated, ongoing program to try to end all nuclear war.

Mr. WAGNER. Yes, sir.

Representative MITCHELL. That's the answer. That other kind of question really disturbs me because you get into some semantics that I don't care much for.

Let me pursue another line of questioning. Several of the witnesses yesterday suggested that a possible best answer to preventing a nuclear war would be to build up our conventional forces. What do you think of that, Mr. Wagner and Mr. Emery? Do you think that would be appropriate?

Mr. WAGNER. It's my view and the administration's view and I think all of us feel that a way in which a war could start which could escalate to the use of nuclear weapons and then lead to the kind of catastrophe that we're talking about is if there were sufficient imbalance in the conventional forces between the United States and the Soviet Union so that in some crisis the Soviets would be tempted to take advantage of that conventional superiority.

So, yes, I think it is an important element of strengthening deterrence to modernize, if I could use that word again, and improve our conventional forces.

Representative MITCHELL. Well, I know Mr. Emery and I don't know you, but obviously to be in a high place position that you have got to be an intelligent and logical and sensible thinking man, and I just—my time is almost up, but I've got to raise the question.

Even is we build up conventional forces to the point that they are on par with the Soviet Union and you still have nuclear weapons, do you honestly, in your gut, in your heart, believe that somebody would not say, "We've got the ultimate. We can stop them." Do you honestly believe that building up huge land forces would somehow or other change the thinking of a nation that has continued to develop nuclear weapons at an astounding rate—change it to the point that it said, "No, we'll charge the San Juan Hill or stay in the trenches of Verdun. We won't dare touch that nuclear weapon." Do you really believe that?

Mr. WAGNER. I think that building up the conventional forces is by no means a guarantee. Nothing is a guarantee. This is a terrible problem, there is simply no question about it, but it is in the right direction for now. The thrust of much of what you have been saying, Congressman Mitchell, is that we should pursue arms control more vigorously.

Representative MITCHELL. That's right, and in a sincere, meaningful fashion.

Mr. WAGNER. Yes, sir; and I believe that this administration, one, has been sincere about it, but there's no way of transferring a feeling of insincerity; but, two, has been taking more effective approaches in the long term, measured over progress in years, not months or weeks and not headline approaches, making it more effective.

Representative MITCHELL. No one would question the sincerity of the Chief Executive and Commander in Chief of the United States, but again, going back by the way I am and I'm down in the ghetto of Baltimore and I see a guy one day who says, "If you do that again, I'm going to rattle my sabre even more loudly." We've heard that for 3½ years almost and then suddenly I'm required to believe—no, I won't even pursue that—suddenly I'm required to believe that's absolute sincerity.

Senator Proxmire has been kind enough to give me 1 more minute and I have just one more question with reference to the nuclear winter.

As I recall, we've got FEMA, the Federal Emergency Management Agency. Do they have any role in this? First of all, they don't do very well in flood disasters. Do they have any role in—or have you thought about their role in a nuclear war?

Mr. **Wagner**. I have talked with FEMA's Advisory Council some months ago, maybe 1 year ago, on what the nuclear winter might mean for FEMA, and perhaps it would be better for them at some point to answer this question themselves.

Representative **Mitchell**. Maybe it would be better.

Mr. **Wagner**. You opened a question of what role the civil defense in general may play here and clearly civil defense—it seems silly to me to think that you could mitigate the terrible effects that have been posed.

Representative **Mitchell**. It seems kind of obsolete to me, the whole operation. It's almost like the guy saying, "If I dig a hole in the back yard and cover it over with dirt"—that's kind of puerile thinking. That has no application to a nuclear winter.

Mr. **Wagner**. You know that the people at FEMA are not in the Department of Defense. I have talked with a number of them over the years. I think their feeling is a very natural one which is that their job is, even if catastrophes occur, try to do the best job they can. And let me say, I think they have been doing a better job over the last few years than any similar agency had been doing before. It's hard to deal with catastrophes if you don't get the practice, but—it really is——

Representative **Mitchell**. I'm taking that in context, but it is amusing if you take it out of context.

Mr. **Wagner**. So I think it's a natural thing for the FEMA people—and I suspect you will hear from them—that perhaps at the margin and suppose that in 2 or 3 years from now we have found some circumstances in which if deterrence were to fail in a certain way in a certain scenario the effects of nuclear winter would not be as pronounced as the worst possible. It seems to me that FEMA's charter would say they ought to take that into account and try to shape the small civil defense program they have to take those kinds of effects into account.

Representative **Mitchell**. I bow to your sagacity and expertise. My own hunch tells me that they are not worth a damn in a nuclear war, that the dimensions of the thing are just so enormous that it's foolish. It's almost childish to talk about civil defense and FEMA. That's over. That's almost obsolete thinking for those who actually can perceive the enormous deaths of a catastrophe that would take place.

I have used up Senator Proxmire's time. Maybe I'll stay a while.

Senator **Proxmire**. Mr. Wagner and Mr. Emery, I'm going to ask Mr. Wagner one or two questions on what I've been pursuing before and then move on to something else, but I do want to ask you about this.

There have been many previous estimates by the Department of Defense of civilian casualties in a nuclear war. As a matter of fact, I think that was part of the posture statement when Secretary McNamara was Secretary of Defense, and also the industrial damage. Those estimates involved only prompt effects. Can you tell us about those estimates?

Mr. **Wagner**. I can't——

Senator **Proxmire**. Is there any reason why they were not continued, why they were discontinued?

Mr. **Wagner**. I don't know that they were discontinued. It may be that——

Senator **Proxmire**. You can't tell me this morning of any and certainly in the posture statements of Secretary Weinberger he hasn't given us any estimates of that kind.

Mr. **Wagner**. Senator, the thrust of the question, it seems to me, is that it is important for us to know in some way whether there will be half a billion or a billion fatalities, but then Congressman Mitchell's point turns around, the thrust of which in some way is what difference does it make; they are both terrible catastrophes and we don't have adjectives to describe them.

Senator **Proxmire**. I'll tell you why. It seems to me that if we get the response that there would be 1 billion immediate casualties and 2 billion ultimate casualties, half the people in the world would perish, that that would give us much more urgency to push for arms control. I'm not sure this administration has that much interest in arms control.

Mr. **Wagner**. I understand that that's the thrust of your question and I know that that's a crucial issue in this hearing and in fact I think it's appropriate that you have said it that directly, Senator Proxmire.

Much of the concern around this issue relates to the perceptions in some quarters—and apparently you share them—that this administration has not been working as actively for arms reductions and arms control as we should have been or as other administrations have been or whatever.

I personally don't share that view and I should perhaps ask Mr. Emery, who represents the Arms Control Agency, to address that.

Senator **Proxmire**. I want to get into that shortly, but there's another aspect to this too. How low a force level would be adequate for deterrence? In view of the nuclear winter findings, it seems to me one aspect of arms control would be to reduce as much as we can the force levels on both sides, but to be aware of your proper concern about having a credible deterrent. So how low a force level would be adequate in your view?

Mr. **Wagner**. I can't give you a quantitative answer.

If the reductions were roughly the same in numbers on both sides and focused on eliminating components of the forces that are destabilizing, I believe deterrence could be maintained at levels that are much, much lower, factors of three, four, five—large factors lower—than what we have today.

Senator **Proxmire**. Mr. Sagan yesterday pointed out that the level that could trigger a nuclear winter is between 500 and 2,000 megatons perhaps, that low. Could we possibly go down to 200 megatons and still have an adequate deterrent if we could negotiate a verifiable agreement with the Soviet Union to do the same?

Mr. **Wagner**. I think the right measure is neither in total yield nor really in total numbers. I think you would have to say what are the characteristics of the weapons, how survivable would they be individually. So it's very hard without taking some steps in that direction to say exactly how far one can go.

I would point out that there is a kind of intellectual construct that one hears along this line of argument that says that at extremely low levels, perhaps a few hundred weapons on each side, which could, if one assumes the worst possibilities of a nuclear winter, still produce these nuclear winter effects, that that would be an unstable regime because it would depend so much on essentially perfect verification, that being able to assure that a country the size of the Soviet Union or the United States didn't have another 2 or 3 hundred weapons hidden somewhere, that that would stress and be essentially impossible to verify and, therefore, those very low force levels would be unacceptable.

Senator **Proxmire**. Well, that would be an element of our vulnerability. If we have our weapons deployed on submarines, for example, and we are confident that they are invulnerable, we could probably inflict an absolutely unacceptable degree of damage with a far, far smaller number of nuclear weapons.

Let me ask you this. Secretary Fred Hinkley has described many of our discoveries of the effect of nuclear war as haphazard and unpredictable. There seems to be general agreement among scientists that our knowledge of these effects have come about in an erratic and accidental way, largely as a result of unplanned revelation and not systematic study, and discovery of such effects as radioactive fallout damage to the ozone, electromagnetic pulse, and now nuclear winter comes about that are cited as examples.

Do you agree that this has been erratic and unplanned, these discoveries?

Mr. **Wagner**. Discoveries are sort of always unplanned. No one can plan a breakthrough or plan a discovery.

Senator **Proxmire**. What I'm getting at obviously, Mr. Wagner, is that there doesn't seem to be any systematic effort on the part of the Defense Department which gets billions of dollars from this Congress and other Congresses to defend this country, to explore this critical area. It should seem to me that you should do it in a systematic, thorough way. We should know what the effects are. You should be able to come up and give us the facts and figures for each of the most likely scenarios. You can't do that.

Mr. **Wagner**. One reason—I personally think that we should and should have had for years a more extensive program in looking at global effects than we have had. I think that not only the Department of Defense but that the scientific community in general ought to be a bit chagrined at not realizing that smoke could produce these effects for as long as they do, no question about it.

Senator **Proxmire**. I appreciate that very much. I think that's a very helpful concession because it does seem to me that the U.S.

Department of Defense as far as we're concerned has the principal responsibility for this. I think the Defense Department—I'm not talking about simply this administration, but for years—has not done the job they should do in this area. In the future we should have a far more detailed understanding of precisely what the effects are—effects of arms control, effects of the deterrent policy, effects of the amount of money we spend, far more important effects of the survival of the species.

Mr. **Wagner**. My personal view, Senator, is that while we should be doing more, we will never get to a position where we can be confident that we understand these phenomena well or there's something we haven't overlooked.

Senator **Proxmire**. I think that's right. I think we would be far better served and have wiser policies if we had more detailed understanding.

Mr. Emery, are there any studies underway in your agency of how arms control might be affected if the nuclear winter findings were valid?

Mr. **Emery**. Well, as a matter of fact, the Arms Control and Disarmanent Agency is participating in an interagency group study now which will——

Senator **Proxmire**. Of nuclear winter?

Mr. **Emery**. Yes. It will be participated in by the National Oceanic and Atmospheric Administration, DOD, and of course the Department of Energy and the National Laboratories. So we are going to be continuing the effort to understand the results of this.

Senator **Proxmire**. What part will the Arms Control Agency play in this?

Mr. **Emery**. We are contributing manpower and obviously some financial resources. We will be participating at whatever level the group assigns us, which could be analyzing policy implications. It could be looking at the various numbers and applying arms control interpretations. I can't give you a complete agenda of what we are doing at this point because it's relatively new.

Senator **Proxmire**. Does that study involve policy analysis or just a scientific study?

Mr. **Emery**. It's a study in particular of scientific analysis but we will of course adapt the information gained to a policy because after all that's our charge.

Senator **Proxmire**. Well, can you give us some examples of how this might affect your arms control policies?

Mr. **Emery**. Well, frankly, Senator, I think it is really too early to give you any valuable information. Obviously, we are going to want to find out what the impact would be on deployments, what the impact would be on design of weapons. These are all things that we would have to examine, but it's just simply too early to tell. As far as arms control negotiations are concerned, we will certainly have to factor the information in, but I can't give you a readout of what policy change it would have.

Senator **Proxmire**. Wouldn't you expect both this country and the Soviet Union and other countries because of nuclear winter findings would be more concerned and more interested in arms control because of the obvious terrible implications, even if the country is not involved itself? For example, countries like China and France and the United Kingdom who have nuclear capability but might not be involved in a nuclear war that could suffer devastating consequences, and wouldn't they therefore be likely to come in on an arms control agreement where they might not otherwise?

Mr. EMERY. There's absolutely no doubt that if the results of nuclear exchange have even a small fraction of the implications that Mr. Sagan and others have presented, of course, it's going to have an impact on the attitude of leaders of nations and public opinion throughout the world. Obviously, it's going to have an impact. The thing that's so difficult at the present time is that we really don't know what the Soviet Union leadership thinks about nuclear winter. We don't know how they factor the nuclear winter phenomena into their planning. We certainly believe that this is just another compelling reason for the United States and the Soviet Union to go back to Geneva and go to Vienna and talk about these issues and try to work out solutions to these various nuclear weapon problems.

Senator PROXMIRE. Is anybody talking to the Soviets about this, whether there's an interest on their part?

Mr. EMERY. I'm not aware of the negotiations or discussions that may be taking place in other parts of our government other than those I have access to, but I'm certain that these issues are going to be talked about. I participated in a conference in Leningrad 3 or 4 weeks ago.

Senator PROXMIRE. It seems to me the Arms Control Agency should be the one to do that.

Mr. EMERY. I participated in a conference in Leningrad 3 or 4 weeks ago at which a panel discussion on this subject was conducted. U.S. reps participated in that discussion. We talked about the consequences of nuclear winter. We raised a lot of these same questions and great concern was expressed. So the answer is, yes. So obviously we are talking about it at the official level. We did just 3 or 4 weeks ago. The great question, however——

Senator PROXMIRE. Before you get away from that—I apologize again to Congressman Mitchell for taking his time. It would be very helpful on the next round, you could tell us who was there, what was discussed and so forth. This is interesting. This is the first time that this Senator has been aware of that participation.

Mr. EMERY. Well, I can provide you a list of participants and I'm not sure whether an official publication has been prepared or not, but I would be happy to find that documentation and get it to the subcommittee.

Senator PROXMIRE. Now there's one other thing that slipped out when you made your statement that I hoped to get after vigorously in subsequent questioning. That is, you said, if what TTAPS—Mr. Sagan and others—discovered to be about nuclear winter turns out to be even partly correct, it's interesting that these scientists have based their judgment and their estimates on data, hard data, which they have gone into in great detail, statistics, and findings, that they have documented, and all of the critics have simply given a theory that someone maybe isn't quite right or it's only partly right, and I would like to ask you and Mr. Wagner later, if you can do so. if you can come up with any contribution of their position which is based on any kind of scientific data. You can always get somebody who can say, well, I'm not so sure it's right; we have to look into it. But all the data that has been presented publicly has tended to confirm the TTAPS position on nuclear winter.

Mr. EMERY. Should I address that at the present time?

Senator PROXMIRE. Let Congressman Mitchell question and then I will come back to both of you gentlemen a little later.

Representative MITCHELL. I have a whole list of things I would like to ask but let me skip and go to basic things. How many weapons do you need to destroy the world? I was just trying to get clear in my own mind. Mr. Wagner, you referred to some modernization of nuclear weapons that's taking place. I kind of want to put it in the context of almost everything that human beings do, they plan an accomplished objective by putting the resources—you know, if we have a cookout, a picnic, we know how many hamburgers we're going to buy so your guests won't be hungry. If you're going hunting you know how many rounds of ammunition you want to carry. That's what I want to get at. How many more weapons do we need? Let's talk about one of your modernized weapons, Trident nuclear sub. Suppose you targeted the cities of the Soviet Union with that sub. How many cities would that sub destroy.

Mr. EMERY. Hundreds.

Representative MITCHELL. Moscow, Leningrad—enough to just about devastate the Soviet Union with only one of the new modernized weapons?

Why then do you need more?

Mr. WAGNER. Survivability is the key, and there are two parts to the answer. I'm afraid I'll be repeating myself in my answer to your previous question. One is that it is our view from what we can infer about the Soviets view of this same question that a response to the Soviet attack on out part which attacks their cities might well not be viewed as a credible response, and they might not be willing to assume that we would carry out that kind of an attack because if it brings in return a third response on their part against our cities. So in some kind of a terrible crisis where all the alternatives were black, the thought is a response on Soviet cities might not appear credible and therefore be a deterrent. Consequently, we structure the forces to be able to attack their military apparatus, their remaining strategic forces, their other military capability. That's one factor in the answer.

The other factor which is in some ways the largest sort of multiplier is the survivability and the ability to be able to absorb a massive Soviet attack and still have enough forces left to threaten not cities but Soviet military capability. There are a number of factors that enter into this assured invulnerability, one of which is a sort of redundancy question. You referred to the submarines and Senator Proxmire earlier referred to the submarines as being invulnerable. Today they appear the most invulnerable of the types of strategic forces we have. But the techniques of antisubmarine warfare, finding submarines continue to be developed by both sides. It's unlikely conceivable in the future that a technique could be found to find those submarines and they are tremendously vulnerable if you can find them. So that is why we have felt that we have needed more than one type of basing to ensure that we would pose the attacker with several different kinds of problems to preclude his being able to destroy all of our forces.

When you take all of those factors together from a relatively small number of warheads that have to be able to penetrate through the Soviet Union to pose the prospect of unacceptable destruction to them, these factors multiply and result in numbers of the size that we have today.

That is not to say that one could not adequately deter at much lower levels provided that there were essential equitability on both sides.

Mr. MILLER. Congressman Mitchell, could I add two points, please, to that? The first I think is that it's important to note that the modernization program involves in many cases the replacement, the retirement, of existing weapons, and so, for example, as part of this overall plan to modernize the bomber force the 75 older B-52 aircraft were retired over the past 2 years. We are taking out our older Titan missiles right now as part of the 1981 strategic modernization plan. And, over the past 4 years, NATO first withdraw 1,000 nuclear weapons from Europe in 1980 and 1981 and we have agreed last October to withdraw another 1,400 weapons unilaterally.

So one point is that this is not simply mindlessly adding weapons on weapons, by it is pulling out older weapons which are not longer credible deterrents.

The submarines, for example—we retired 10 nuclear missile submarines at the end of the 1970's and the new submarines that are coming on line only now replace those. So there's a replacement process going on here.

The second point is to amplify what Mr. Wagner said on deterrents at lower levels. One of the questions I think that you have been asking is are there too many nuclear weapons in the world today.

Representative MITCHELL. I know there is today. Yes, if you have one.

Mr. MILLER. The answer is, yes. Two points that I'd like to make in that regard are about the current armaments reduction proposals which we now have on the table. In the strategic arms reduction talks and the START talks, our proposal was to slash by one-third the nuclear ballistic missile warheads on both sides. This is the deepest reduction ever proposed and in the INF talks, the European talks, the United States proposed eliminating that entire class of long-range INF nuclear weapon systems.

So, yes, we could go even lower, but we need Soviet agreement first to our current deep cut.

Representative MITCHELL. I understand exactly what you're saying. You're making it very clear to me and I'm not denigrating the responses of either of the two of you. I've just got to go back to the philosophy and the logic. I really have. If you tell me that one nuclear Trident submarine could wipe out hundreds of cities in the Soviet Union and that would not be credible to them, it's a little difficult for me to follow that. Don't try to school me on this because I'd have to do a lot of work, but I guess, Senator, my reaction to all of this has been—and I'm not—please, I'm not depreciating any of your statements. The bottom line reaction has been the utter folly of pursuing this whole thing. That's what it all says to me. We've got the Trident submarine to establish credibility and it just seems to me that you've established a—perverted is not the word I want, but some kind of logic which says we've got to keep on going, keep on building modernizing, even though we know the end result of all of that effort might threaten the extinction of the human species. You give me pause to think and I'll be a little better prepared the next time, not in terms of the expertise of weapons, but I want to be a little better prepared in terms of a logic that says we can destroy Leningrad or Stalingrad, Moscow, and that's not credible.

Thank you, Senator.

Senator Proxmire. Thank you Congressman Mitchell, for a very illuminating statement.

Mr. Wagner, you say in your statement that the attitude of the technical community indicates that there could be a nuclear winter or there could be little effect. Have any scientists published studies supported by data showing that there would be little effect on climate from nuclear war at or above the threshold of the nuclear winter study?

Mr. Wagner. Yes. In fact, Senator, there have been. There's one particular article published in Ambio. There are those who argue that the combinations of the ranges of a dozen or so major variables——

Senator Proxmire. Could you tell us which article in Ambio? We have Ambio.

Mr. Wagner. I've forgoten. I don't have it with me, sir.

Senator Proxmire. May I say the Ambio article supports the nuclear winter thesis.

Mr. Wagner. I've forgotten. I don't have it with me, sir.

Senator Proxmire. May I say the Ambio article supports the nuclear winter thesis.

Mr. Wagner. There have been a number of things published in Ambio. There have been statements and refutations. A point that I think gets to the heart of your question, though, is that—let me preface it by saying that my personal expectation is that after we do all this work we will find that in most scenarios and most combinations of the uncertainties of the variables that there will be a nuclear winter, even for rather low, small scenarios.

My only point is that there is today a range of uncertainty. There are perhaps a dozen variables that make a difference. How materials would burn, how much burnable material there is, how it would be elevated into the atmosphere, how much of it would be rained out, how it would circulate, how passive the atmosphere would be.

Senator Proxmire. Mr. Wagner, would you tell us what you meant when you said "little effect of nuclear winter?"

Mr. Wagner. Yes, sir. If one takes the most optimistic end of the range of the uncertainties in these many parameters and combines them, one can arrive at a result that says very little effect.

Senator Proxmire. By "little effect" you mean only a small drop, for example, in temperature?

Mr. Wagner. Probably, or of not long duration.

Senator Proxmire. Say 2 or 3 or 4 degrees?

Mr. **Wagner**. Maybe something of that order.

Senator **Proxmire**. Yesterday we were told that a drop in temperature of 6 degrees would virtually wipe out the wheat crop in the Northern Hemisphere.

Mr. **Wagner**. That would be a catastrophic thing. That's exactly right.

Senator **Proxmire**. Well, it wouldn't be little effect then. It would be a profound effect, even though it would be at the optimistic end of the nuclear winter theory.

Mr. **Wagner**. It would be of the same order as the many other effects that we have known for years would be produced by nuclear war. The fallout effects and ozone effects and so forth. It would not dominate the global effects at that range at the most optimistic end. It would not dominate the global effects.

Senator **Proxmire**. I think it's very helpful that you have agreed as a representative of the Defense Department that there will be a consequence and it could be significant, and I welcome that.

I would like to do something that's a little unusual here, but I hope you will forgive me. Mr. Sagan is in the room and I'm going to ask him to respond to what you have said on this issue because he, or course, is a specialist in this area and I think it would be very helpful to the subcommittee and the record if we could have his response here if he would like to give it to us. Mr. Sagan.

TESTIMONY OF CARL SAGAN, PROFESSOR OF ASTRONOMY AND SPACE SCIENCE, CORNELL UNIVERSITY

Mr. **Sagan**. On the remarks that Mr. Wagner just made, I have almost no disagreement at all. I have been taking notes and as far as I can tell I am in pretty good agreement with almost everything he has said. There is a range of uncertainty in the calculations. We hope that the range will be narrowed. I think there will always be some residual uncertainty. That uncertainty itself has strategic significance. I also agree that when all is said and done—bear in mind that this is not a problem amenable to experimental verification, at least not more than once—that the consensus will be that even in the optimistic cases there will be a residual serious effect. But at the most optimistic end of the range of plausible outcome, that effect probably would be comparable to the lives lost by prompt effects.

If I can remark on a couple of other statements made—that how many nuclear weapons there are in the world is classified and so on—the estimates made by Secretary of Defense Brown a few years ago, with some extension for what has happened since then, suggests that the number of strategic and theater nuclear weapons in the world are pushing 18,000 and the total number of nuclear weapons all together, that is including tactical nuclear weapons, is somewhere around 50,000.

I am not privileged to classified information, so I can proceed easily on the subject. I don't know whether Mr. Wagner may have other numbers.

There have been several remarks about how the United States has unilaterally removed nuclear weapons from Europe and elsewhere—those are all tactical nuclear weapons. If you look at the curves published by the Department of Defense on the number of strategic nuclear weapons as a function of time, you find that both the United States and the Soviet Union numbers have been steeply increasing in recent years. Extrapolations that have been made, not by the Department of Defense, show those numbers continuing to increase—that is, strategic and theater nuclear weapons, not tactical weapons.

If that isn't the case, it would be very good to have some published curves of what DOD or ACDA believes correct.

If I may make just one other remark, I also was in agreement with many of the remarks made by Mr. Emery from ACDA. I was delighted to see that nuclear winter is being taken seriously both in the DOD and the ACDA. Mr. Emery said something about participating in a discussion with the Soviets in Leningrad 3 or 4 weeks ago. There was a SCOPE meeting in Leningrad at roughly that time. It's an international scientific group. If there's been official discussions with the Soviets on nuclear winter, it would be very good to know about that.

I would also be interested in knowing when the Air Force document on the doctrinal implications of nuclear winter will be available.

Senator PROXMIRE. Thank you very much. Mr. Sagan. That's most helpful. I understand you're going to give us for the record your report on that meeting in the Soviet Union?

Mr. EMERY. Yes, I will. Perhaps it would be appropriate for me to give you a sentence or two now to tell you what the conference was. It was a well designed conference sponsored by the United Nations, which took place in the Soviet Union. It was, I believe, the first time that such a conference had been hosted by the Soviet Union. I headed a delegation of American officials, two from ACDA and two, if I remember correctly, from the State Department. I myself did not participate in the panel on the nuclear winter, but we did have representatives from the State Department who participated in all of the working group sessions.

I think all of us were very encouraged by the fact that we had an opportunity to discuss a variety of options and examine the issues and, as I indicated, the panel was devoted to the nuclear winter phenomena for an entire afternoon, so it is a subject of continuing interest on our part and, of course, the Soviet Union and the United States did get a chance to exchange some views directly at that time.

Senator PROXMIRE. Mr. Emery, many polls in the country and many States referenda have shown overwhelming support for negotiating a neutral verifiable nuclear freeze with the Soviet Union on nuclear weapons. In my State the vote was 75 percent in favor with bipartisan support. There's nothing partisan about it. But that position is strongly opposed by the administration and it was defeated, as you know, in the Senate, although it passed the House almost 2 to 1.

Would it make any difference in your Agency's view about that nuclear freeze if the nuclear winter findings were shown to be correct?

Mr. EMERY. I don't think the nuclear freeze, Senator, is going to be a satisfactory response to the problem. Rather than rehash all the arguments against the nuclear freeze, which we certainly could do it if you like, let me simply say that the Arms Control and Disarmament Agency and the administration feel that there are better alternatives that would result in great stability and a much lower number of nuclear weapons. It seems to me that if we went to a nuclear freeze we would freeze all the weapons in place and all the instability in place that exist presently.

Senator **Proxmire**. But everybody who's for a nuclear freeze argues that it's the first step and it would be followed with reductions negotiated but the first step is to stop the arms race, and it would do that.

Let me just ask you about that part. Would there be any change in views because of the nuclear winter findings with respect to your attitude toward a comprehensive test ban, including taking the kilotonnage down from 150 kilotons down to zero?

Mr. **Emery**. Senator, that's a long-range goal and I can assure you that these findings, both in terms of goals for nuclear testing or INF negotiations or START negotiations or any other nuclear related negotiations, will reconfirm to us the importance of deep, substantial reductions on both sides, as opposed to freezing where they are today. We have proposed in this administration the most sweeping reductions in nuclear weapons that any previous administration has proposed, and we would find that the study that Mr. Sagan and others have concluded would certainly reinforce the need to achieve those great reductions and we are willing to do that.

Senator **Proxmire**. Well, I take it you have an open mind on everything and the President has always said everything is out on the table.

Mr. **Emery**. Exactly.

Senator **Proxmire**. Are there any conceivable effects of nuclear war that could cause you to change your position toward the freeze proposals?

Mr. **Emery**. I think that if we were to confirm all of the horrible consequences that Mr. Sagan and others have outlined, it would reaffirm even more to us that nuclear freeze is totally inadequate to reverse the trends.

Senator **Proxmire**. It's inadequate because it doesn't reduce weapons?

Mr. **Emery**. Precisely. It's inadequate because it doesn't address the imbalance.

Senator **Proxmire**. Do you see anything contradictory? Wouldn't it make it far more plausible in the future and more logical once we achieved that level of agreement, stopped the arms race, to stop the testing, stop the production, stop the deployment of nuclear weapons, we could then proceed to reduce the number?

Mr. **Emery**. Senator, I would have to conclude that negotiating a nuclear freeze would probably be as difficult and would take as long to negotiate as would very substantial reductions in the stockpile. The fact of the matter is, you have to decide what to freeze and how to freeze.

Senator **Proxmire**. There's no reason in the world why you couldn't do both at the same time.

Mr. **Emery**. Well, I am convinced that the best way to approach the issue is to focus on those particularly dangerous and destabilizing systems, those weapons that have capability of throwing huge amounts of dust and smoke and radioactive material into the atmosphere, to concentrate on those imbalances that can cause one side or another side to become trigger happy or insecure. It's not simply the question of holding the line where we are today because there is no guarantee that you would be able to move along from the freeze to accomplish the deep reductions that we feel ought to be the focal point.

I see absolutely no reason to spend time negotiating a freeze that would essentially lock us into the dangerous situation that we have today where the Soviet Union——

Senator **Proxmire**. I'm not talking about locking us in. I'm talking about stopping the arms race and proceeding. Everybody—I don't know anybody who favors the freeze who says that's all you have to do. You're absolutely right. If we decide we'll stay at this level, it's a terribly dangerous level. But as I say, it's not only contradictory, it seems to me that's the most productive and most encouraging way to get at reductions, to stop the arms race in the first place.

Mr. **Emery**. You see, I'm not convinced, Senator, that if we negotiate a nuclear freeze that there would be sufficient incentive to the Soviets to move ahead rapidly to resolve the very difficult problems that yet remain. We can freeze because freezing essentially doesn't require the Soviets or the United States to think about how to solve the problem. That's why they talk about a nuclear freeze, because it's something that they feel would not require them to look at the issue of stability, wouldn't call upon them to address their heavy missiles, wouldn't force them to address the issue of force structure which are particularly important.

What we are asking the Soviets to do is move ahead with us, to look further down the road at the situation that we really want to create, which is substantially fewer of the most dangerous weapons, a balance of power which is more stable, and to address those MIRV systems and other systems which we find particularly dangerous.

I just think we would waste time and possibly take away the impetus and the incentive to move ahead to these other issues.

Senator **Proxmire**. Mr. Emery, it's very, very hard for me not to argue with you because I feel strongly about this, but I'm not going to. I think you have stated your position very well. You've made the record clear. You're absolutely intransigent on the freeze; there's nothing that could change your position or, in your view, the position of the administration. So let's proceed ahead and let me ask Mr. Wagner a question.

Will the results of the research into the nuclear winter findings being supported by the Defense Department be made available on an unclassified basis?

Mr. **Wagner**. Let me make a distinction between reducing the technical uncertainties in the variables that are part of the problem, such things as modeling the climate and so forth, modeling the circulation of the atmosphere, as distinct from looking at various scenarios and taking the models of the phenomenon and seeing what the answer would be for various scenarios.

All of the former category, the technical work, no question, it will all be published and unclassified. I can imagine in the future that we might in fact, want to look at scenarios which are let's say, very close to particular targeting plans, and those might have to be classified, although I'm certain that the efforts will also involve looking at scenarios and the result of that, most of that, will be unclassified.

Senator **Proxmire**. Are there any studies underway at the Department of Defense of the policy implications of the nuclear winter findings and, if so, can you tell us who is doing them and discuss them?

Mr. **Wagner**. Yes, sir. There are three or four. Professor Sagan referred to one at the Air War College at Maxwell Air Force Base. The Defense Science Board has a task force looking at this question and the Defense Nuclear Agency has two, and possibly more contracts, with study organizations to look at the policy implications.

Senator **Proxmire**. Can you give us any idea when those studies will be available?

Mr. **Wagner**. I would say that they would be on the order of a year.

Senator **Proxmire**. In the order of what?

Mr. **Wagner**. A year, and let me say why, Senator. Most of them, and in fact the places in this problem where there are likely to be policy implications are in studying what I might call the detailed structure of the nuclear winter problem.

Let me give you an example. One of the ideas that is perhaps somewhat unfortunate in describing this is the idea of a threshold. I have used the term myself and so have you. If there were in fact a sharp onset of these phenomena, I could imagine that that would lead to wanting to put together targeting plans and changes in hardware—let's say missile accuracy—that would allow you to deter at that threshold, whereas if there is a continuous range of variation and there is no threshold, then I think that might have different implications for targeting and crisis stability. Those kinds of details I think require a better understanding of a technical phenomenon before we can really explore it in the policy sense and since I believe the technical phenomena will take years to sort out, that's why it will take us a while for the policy implications.

Senator **Proxmire**. Mr. Emery, I realize it's a policy to achieve reductions in the number of nuclear weapons on both sides. If it were not only in our interest to do so, and necessary for our national survival, would it make any difference in our approach to arms control?

Mr. **Emery**. Well, the approach to arms control is constantly under review. Since I have been in the Arms Control and Disarmament Agency these last 15 months or so, nearly on a daily basis we have reviewed certain aspects of our arms control policy. So, of course, we would alter our arms control policy as dictated by the situation, as dictated by the facts.

Senator **Proxmire**. But I'm talking about the number of nuclear weapons might be so great on both sides—is so great on both sides obviously, that its use would trigger a nuclear winter that would destroy either side that initiated it. Under those circumstances, shouldn't that make a difference in arms control agreements?

Mr. **Emery**. Well, it seems to me that we are already pursuing the sort of policy objectives that are designed to move in the safer direction, and that is deep reductions in nuclear weapons areas. I think the testimony that I read from yesterday's hearing and comments that I read this morning, indicate that everyone is in general agreement that the thing to do is to eliminate the huge numbers of nuclear weapons that are deployed on each side, and our policy is aimed at doing that. We are trying to convince the Soviet Union to come back to the negotiating table and join us with a comprehensive agreement to eliminate the huge numbers of nuclear weapons and move to a safer, more stable balance at a much lower level. And I think that is exactly the direction that the nuclear winter phenomena would argue for and I think that we are all in agreement that that's what we want to do.

Senator **Proxmire**. Mr. Wagner, some people have raised questions about the scenarios and assumptions in the nuclear winter study. For example, Leon Gouré, in an article last December and Sam Cohen more recently concluded that the scenarios are not realistic because they assumed cities would be targeted.

Yesterday we were told by a very expert panel that while cities themselves would not be targeted, the targets near cities, forests, and complexes would burn and therefore there would be widespread fires of the kind described in the nuclear winter study. Do you agree with that?

Mr. **Wagner**. Yes. Cities are not targeted, but there would be fires.

Senator **Proxmire**. Thank you, sir. Now in your view, are the scenarios and megatonnage used in the nuclear winter study realistic or unrealistic?

Mr. **Wagner**. As I said earlier, there is a range of possibilities for nuclear war and that range is so wide and so diverse that hardly any scenario is completely realistic. There may be others that maybe haven't been looked at yet that come closer to the details.

Senator **Proxmire**. When you agreed that cities might not be targeted but that the targets that would be hit would be near enough to cities, do you mean that the cities themselves would burn totally?

Mr. **Wagner**. I don't know whether they would burn or burn totally. The question as to how the fires would spread and how many fires there would be are among the technical uncertainties that we would have to solve.

Senator **Proxmire**. Well, wouldn't you agree that if we have industrial targets that they are in cities very often?

Mr. **Wagner**. Yes, sir; and there would certainly be fires in cities. How much they would spread and how extensive they would be depends both on the targeting uncertainties and on the target variables and on physical variables.

Mr. **Miller**. And whether specific retaliatory strikes of that sort were in fact ordered.

Senator **Proxmire**. But if we target industrial targets, we're targeting cities.

Mr. WAGNER. By not targeting cities, I meant to say that we do not target for fatalities, cities as such. Of course, there will be fires in cities.

Senator PROXMIRE. Mr. Wagner, you said that our nuclear stockpiles in terms of megatonnage and number of weapons is lower now than 20 years ago. Of course, that's correct. Is it not true that our stockpile of nuclear weapons now is growing and will continue to grow in future years?

Mr. WAGNER. No, sir. In fact, our plans show that they stay about level.

Senator PROXMIRE. Well, they grow some, though. The figures I have seen indicate that there's some growth.

Mr. WAGNER. There is perhaps some growth during the next few years, but it's of the order of a few percent, I think. It's not the kind of continual unending growth that some of the popular projections show. It will not exceed—in fact, it will not approach the maximum that we achieved in 1963 or something like that.

Senator PROXMIRE. In a way, that's academic as far as nuclear winter is concerned because they are obviously far above the threshold.

Mr. WAGNER. Oh, yes, sir.

Senator PROXMIRE. Mr. Emery, if the conclusions from the study and progress indicate that there's a contradiction between the deterrence that is now being pursued and national survival, would you be willing to modify your approach to deterrence so far as arms control is concerned?

Mr. EMERY. Certainly with respect to the question, but depending on what the data shows, of course, we are going to have to respond. Let me simply say that I can't envision any study that would invalidate deterrence because I think the bottom line is we are never going to know, or at least in the very near future, exactly how the Soviet hierarchy looks at the doctrine of deterrence in light of the nuclear winter, and the fact of the matter is, there are an awful lot of questions that need to be asked and answered. But, of course, the Arms Control and Disarmament Agency and in fact the Government is going to have to look at all of these factors in order to put together the very best arms control and military philosophy that will make the world safe and at the same time defend our national interests against a variety of threats that are plausible and that we have to worry about.

Senator PROXMIRE. Now in your statement you say that it is our goal to make nuclear weapons obsolete.

Mr. EMERY. That's correct.

Senator PROXMIRE. If present options for using nuclear weapons were shown to be self-destructive because they would cause a nuclear winter, would that make them obsolete.

Mr. EMERY. It would depend on whether or not the Soviets reacted accordingly and met with us in Geneva or somewhere else and reduced the number of their weapons to our low level. I can't conceive of a situation where the United States would unilaterally decide that its military deterrent would alone cause a nuclear winter and hence that we could simply do away with ours without the Soviets doing away with theirs.

What we are talking about is a combination of factors that have to be addressed and it would seem to me that if the United States and the Soviet Union are able to sit down in Geneva and reduce the number of nuclear weapons by an order of magnitude or more, that would be a very desirable thing to do, but it's not something that the United States can or will do in a vacuum and it's not something that the Soviet Union can or will do in a vacuum.

So the nuclear winter findings reinforce the importance of going to Geneva and negotiating very deep reductions, especially in destabilizing systems. That's how I envision the nuclear winter impact, as hopefully a catalyst for both sides to get back to the negotiating table, pick up where we left off last year and put together an arms control regime that can accomplish what I think every sane, sensible person in the world wants, and that is elimination of these weapons if at all possible and reducing at least or hopefully eliminating the risk of war.

Senator PROXMIRE. Mr. Wagner, would it make any difference in the kind of strategic options considered by the Defense Department that one of them would bring about a nuclear winter if you used it?

Mr. WAGNER. If by that you mean changes in the philosophy of deterrence and how we think about what would deter the Soviets, I think, as Mr. Emery just said, the basic philosophy I doubt will change. The details I can imagine might change. One might find that there were certain scenarios in which you would want to try to enhance the stability of the scenario by reducing the effects of the fires and so forth.

Senator PROXMIRE. So you would be searching for weapons which would have, for example, perhaps greater accuracy and less megatonnage, less fallout, is that right?

Mr. WAGNER. I think that is almost inevitable, that this will cause us to look at those kinds of directions. An obvious criticism of that is that it would be, to use kind of a flip term, making the world safe from nuclear war. That would not be the objective of looking for such changes in the forces and in accuracy. The objective would be to try to enhance crisis stability as it might be influenced by nuclear winter.

Senator PROXMIRE. Mr. Wagner, I realize there may be a dilemma over an option such as counterforce which is considered necessary to maintain deterrence and the fact that employing this option would cause our own self-annihilation if the nuclear winter findings are valid. Do you agree that there's a possible dilemma and do you have any thoughts on how to resolve it?

Mr. WAGNER. There is a dilemma in the entire question of nuclear weapons which you have stated in a number of different ways. The dilemma is that in order to insure deterrence we maintain forces that can threaten catastrophic response, but if in fact deterrence were to fail, then the situation would in fact be catastrophic. This particular phenomenon I think does not really qualitatively change that dilemma. That's been with us for many years. It may change the details, but we will have to see.

Senator PROXMIRE. Mr. Emery, in a nuclear winter nations uninvolved and distant from any nuclear conflict could collapse without a single bomb being dropped on their territories. As this understanding sinks in, it seems probable that the five nuclear powers will come under increasing diplomatic pressure. Do you believe this pressure could play a positive role in arms control and disarmament discussions, given our new understanding that they too have a life or death interest in the outcome of these discussions?

Mr. **Emery**. Well, there again, Senator, let me say that I think it's an additional factor that is certainly going to provide some impetus for getting back to the business of negotiating and resolving these problems. I have to say, though, I have traveled extensively during the last year or so. I have been on all but one continent. I have spoken as far away as Australia and New Zealand and traveled extensively to Europe and I've been to the Soviet Union since I've been in the Arms Control and Disarmament Agency, and wherever I go I find there is a tremendous concern about the arms race, about nuclear war, and about the possibility of some brash, insensible act.

Senator **Proxmire**. Now these countries can see it—Australia can see it and African countries can see it and Asian countries can see it, that without their being involved in the slightest way, they can suffer an incredibly destructive and terrible environmental catastrophe—absolute famine, starvation——

Mr. **Emery**. Well, I have to say that there is yet another dimension of the phenomenon which people have understood and realized for 20 or 25 years.

Senator **Proxmire**. Now they understand it. The nuclear winter just came up. Don't you think in some of these countries they thought, well, if there's a nuclear war, that's fine because we're not going to be involved?

Mr. **Emery**. Well, as I say, it's an additional dimension, but I can remember the movie "On The Beach" sometime in the past and I can remember a number of others.

Senator **Proxmire**. Well, that was Nevil Shute and it was a terrific movie. I didn't read the book. And it was very, very moving, but that was fiction. This is now the most eminent scientists in the world who are agreeing and we have the Defense Department representative saying this morning that in his judgment this is probably going to turn out to be verified and correct. It's a fact now.

Mr. **Emery**. Senator, all I can say is that if you read Jules Verne or H.G. Wells, you find there are a number of fictional writers who have in some way presaged developments in our modern era. The point is simple that there is a heightened level of concern about nuclear arms and warfare and this is another dimension which, if it is taken seriously, if the Soviet Union will come back to the negotiating table, and if our nations to the east and nations to the west will give their encouragement and support and push, I see absolutely no reason that we can't get back to the negotiating table and move very substantially in the right direction.

At the present time, as you know, we have told the Soviet Union that we are making no preconditions to their participation in nuclear arms talks. The door is open. We have neogtiating teams on hand. We are willing to start at a moment's notice. We are asking for an open agenda in Vienna in September where we will appear so that we can talk about a variety of issues. We are very anxious to begin that dialog because we see that dialog as a very, very important step to resolving the threat and the problem and the fear that many people have which has been heightened by the nuclear winter phenomena.

Senator **Proxmire**. Mr. Wagner, is the Defense Department now studying whether it would make sense to adopt a no first use policy on nuclear weapons or is it the view that first strike is a viable option no matter what the effects are in a nuclear war?

Mr. **Wagner**. Mr. Chairman, there is a distinction between a first strike and a first use. First strike means an ability to disarm the retaliatory capability of the adversary.

Senator **Proxmire**. Well, perhaps I misused first strike. First use. Obviously, the scenario most commonly used is that the Soviet Union should move in Western Europe with their great tanks and so forth, move toward the channel, and we might react with tactical nuclear weapons so we would preserve that first use.

Mr. **Wagner**. We continue to believe we must preserve that option as a contingency in the event of a conventional or nuclear attack on the part of the Soviets.

Senator **Proxmire**. Is there any study of the very likely escalation under those circumstances if we use it for retaliation?

Mr. **Wagner**. Senator, we look at those issues all the time in many ways, yes.

Mr. **Miller**. And, Senator, it is worth noting for the record that the current NATO Policy is not only endorsed by the U.S. Government but by all of the governments that participate in NATO. That is, that the policy of flexible response is the best way to deter both nuclear and conventional aggression.

Senator **Proxmire**. I realize that, Mr. Miller. You're absolutely correct. As I understand it, that's the unanimous position, but it seems to me that that unanimous position might very well be reexamined under these circumstances. After all, we have a new dimension now to nuclear war, an environmental dimension that should be of overwhelming significance.

Mr. **Wagner**. Senator, it sounds to me as if you are arguing for our adopting a policy that we would believe would make war more likely.

Senator **Proxmire**. No, I'm certainly not doing that. I realize that to do this we can't do it lightly, the fact is that there is that preponderance. What's our problem here. Our problem in the scenario I discussed is that the Soviet Union has a conventional weapons preponderance. If we remedy that preponderance it may cost a lot of money. If we remedy that situation, then it seems to me we could accept the no first-use doctrine.

Mr. **Wagner**. Perhaps if we got to the point where there was essential parity conventionally we might want to consider that, but that's a long way away. We are trying to move in the direction of strengthening the conventional forces. We don't see the prospect of moving away from the flexible response posture.

Senator **Proxmire**. Well, let me ask you this. Are there any possible effects of nuclear war, whether a nuclear winter or some other catastrophe, that would change our nuclear war-fighting options?

Mr. **Miller**. We don't have nuclear war-fighting options, if I could make that point. The policy is always to present the Soviet aggressor——

Senator Proxmire. You just told us you have one option. You may use or you reserve the right to use—it's an option—tactical nuclear weapons if the Soviet Union is winning a war in Europe.

Mr. Miller. The whole point of that is that is to say to any Soviet planner that in any contemplated level of attack the Soviet Union cannot expect to gain more than it would lose in retaliation, thereby to prevent such an attack.

Senator Proxmire. Well, let me ask it this way then. Are there any possible effects of nuclear war such as nuclear winter or other such catastrophe that would change our nuclear war strategic war fighting options?

Mr. Miller. Again, I would have to respond, Senator, that the entire point is to prevent Soviet aggression. If we can prevent the Soviets from attacking us or our NATO allies, there will be no use of nuclear weapons; there will be no nuclear winter.

Senator Proxmire. But your objections to the war fighting would change our strategic options?

Mr. Miller. Mr. Wagner has indicated there may be some changes in the details of some of the retaliatory options, but I would want to reemphasize that the thrust of the policy which is to present the Soviet leadership with the clear evidence that whatever option of aggression they might choose, conventional or nuclear, that the cost would be greater than the benefits. So we don't change in that overall thrust in our policy.

Senator Proxmire. One of the aspects of nuclear winter that we haven't really thought about and the Defense Department, it seems to me should, is that if you have a nuclear winter you move your military forces in an entirely different kind of situation—blackness, darkness, terrific cold, and maybe very great difficulty communicating as well as transporting people. We were told the command control would not be possible in a protracted nuclear war due to the nuclear winter phenomena. Do you agree with that?

Mr. Wagner. I think that that is a matter that needs a further look. It is certainly something that we intend to look at and one of the things the Defense Science Board is studying is that particular question. It's not clear that it's impossible. It is clearly horrible. Whether or not we would want to structure a position to regain some capability is something that I think we can't say yet.

Senator Proxmire. Mr. Emery, you told us about the conversations in the Soviet Union. If the nuclear winter findings prove true, the first people who should know about it are the Soviets since they are the ones that are building up the first strike capability. Have you or anybody in the administration been talking to the Soviets about the nuclear winter findings?

Mr. Emery. Well, as I say, this discussion that's taken place at this conference that admittedly wasn't an exchange between high level government officials, but I can assure you that as soon as we can get the results of our studies it will, of course, be a matter of some discussion because obviously it will impact on a variety of factors in dealing with the Soviets in arms control.

Let me say that both sides have discussed the issue at various times unilaterally and we are aware of certain Soviet studies that have been conducted and I'm sure the Soviets are aware of the work that's been done by a variety of scientists in this country and undoubtedly are aware that the U.S. Government is in the process of studying the phenomenon.

I guess what I would say is that in my opinion it is not necessary to wait until we have all of the final results from such a study before we could conclude that the best thing to do is to start negotiating again because there are a lot of reasons—nuclear winter notwithstanding—that would argue strongly for moving ahead in the area of reductions.

Senator **Proxmire**. But we're moving awfully slowly on this, aren't we? It will be a year or so before we have nuclear winter findings and then discuss the significance and the options and so forth with the Soviet Union.

Mr. **Emery**. Well, let me simply state, as I said a moment ago, I don't think it's necessary for us to wait until all the "i"s are dotted and the "t"s crossed before we can conclude that even a minute fraction of the phenomenon that's been described will be more horrible than we dare contemplate. So I think we can conclude on the basis of what we have already heard that we need to move ahead in the negotiations and move to a safer lower level of nuclear weapons and I don't think we need any additional studies to tell us that.

What we really need to know, of course, is as much as we can about the facts and to draw as many conclusions as we can from the tremendous amount of scientific study that goes on.

Let me also say that as with many theories that are not provable in the laboratory, as Mr. Sagan mentioned a while back, debates can range over the particular numbers and details for years and years. I'd like to borrow from some of my knowledge of astronomy—arguments related to the steady state universe versus a dynamic expanding universe have been going on essentially until very recently and Hoyle and others are still adhering to certain aspects of that theory. There's a debate going on now relative to whether the universe is open or closed. This debate has been going on for some period of time. And I suspect that it will in the future. But that doesn't prevent us from drawing certain conclusions that are very useful in determining other scientific effects.

So I would just say that I don't think we have to wait 2, 5, or 10 years, or a long period of time to draw the conclusion; I think all of us can draw a conclusion here, and that is, the best way to prevent the disasters that have been outlined is simply to move ahead with nuclear negotiations at the highest possible level and to use whatever diplomatic pressures or any other kind of pressures that are appropriate to encourage the Soviet Union to come back to the table with an open mind and for us to go back to the table with an equally open mind and move toward making the world safer with fewer nuclear weapons.

Senator **Proxmire**. Mr. Emery, the Soviet scientists as well as the American scientists have studied this nuclear winter phenomena and they've worked together on it and they've worked separately too. They have had similar conclusions. Shouldn't the President of the United States challenge the Soviet Union to come back to the bargaining table on this particular issue? I realize he's challenged him to come back and said the door is open and so forth. Why shouldn't he use this relatively new development which both scientific communities in both countries largely accept, in view of the catastrophic effects, not just on the Soviet Union and the United States, but on everybody in the world?

Mr. **Emery**. Well, my opinion is that this can be useful leverage. Just how the President might use it or how the Arms Control and Disarmanent Agency or the State Department might use it is a matter of strategy.

Senator **Proxmire**. You're the Arms Control and Disarmament Agency. Why doesn't the Arms Control and Disarmament Agency propose it to the President of the United States?

Mr. **Emery**. Well, what we are doing is waiting for some initial findings at least to quantify the theory and we may have policy recommendations to make.

Senator **Proxmire**. Will you wait a year?

Mr. **Emery**. I'm not going to quantify the length of time. Our recommendation to the President already is to move ahead with negotiations. We advised the President to encourage the Soviets to discuss the use of various nuclear disarmament issues as soon as possible. Consequently, we are encouraging the Soviets to discuss them in Vienna, September 18. Yesterday is not soon enough for us. We want to raise these issues and resolve this problem as quickly and effectively as we can. And inasmuch as this can be a catalyst, an incentive, if that's all, it will be a very helpful thing.

Senator **Proxmire**. Mr. Wagner and Mr. Emery, I just have a couple more questions and I apologize for detaining you as long as I have. You have been very responsive witnesses and I appreciate it very much.

Mr. Wagner, isn't it correct that in a war with the Soviet Union, you would avoid attacking their cities because they would retaliate by attacking ours, and doesn't this demonstrate we have made decisions about the options we would employ based on the effects of nuclear explosion? If we change our options because our cities might be destroyed, why wouldn't we change them because our climate might be destroyed?

Mr. **Wagner**. The issue that you touched on is the issue of maintaining a credible deterrent and what we have been saying this morning repeatedly is that we believe that we really must continue to do whatever we can to maintain credible deterrence.

Now, to some extent, the credibility is in the mind of the Soviets and in the eyes of the Soviets. I would suggest that we may never know how the Soviets view the strategic meaning of the nuclear winter phenomena. The one way that we can perhaps infer that they are taking it seriously is if they will sit down and negotiate with us.

Senator **Proxmire**. Mr. Emery, are there any conceivable effects of nuclear war that could cause you to change your approach to arms control?

Mr. **Emery**. No. I think our approach to arms control is already very sensitive to the effects of nuclear war. Whether it's the holocaust of the kind described by Mr. Sagan and others with the aftereffects or whether it's a detonation of a smaller number of weapons, the fact of the matter is that the use of nuclear weapons is a horror that we want to avoid and, as I outlined a few minutes ago, I think that the proper course of action is for us to negotiate and to try to find the common ground that will lead to reductions of the kind that the administration has proposed or even more reductions. So I think we are sensitive to that and we are working diligently to devise effective policies, negotiable proposals, that will move us in that direction.

The point that I would have to add, adding I think to some of the comments Mr. Wagner made a few minutes ago, is that we can't do this in a vacuum. Even if we decided that every horrible effect of nuclear winter were 10 times worse than it's been described, it's going to be impossible to solve the problem unless the United States and the Soviet Union work together. I don't believe in unilateral disarmament and I don't believe the Soviets do either. So we have to understand that the reduction we need in order to create stability and peace is not going to happen unless both sides sit down at the negotiating table and find ways to reduce and to achieve a much lower level of nuclear force than we have today.

Senator PROXMIRE. Mr. Emery, I was just going to say that your agency, the Arms Control and Disarmament Agency, has been involved, as you said, in the nuclear winter studies. Frankly, I'm not exactly sure why, because you maintain—if you're serious about the studies and the deliberations now underway in the light of the nuclear winter findings—but I don't know how you can do that if you do not acknowledge that our arms control policy cannot or will not be modified no matter what the studies show.

Mr. EMERY. I don't think anybody said that. I haven't said that. What I said was that we are moving in a direction that I think is an appropriate response to the problem. I think I said several times during my testimony that we are reviewing information, that we are flexible, that we are constantly examining the policies that we have, and that we are willing to examine and propose new ideas as may be necessary to solve the problem.

Senator PROXMIRE. But you say that nothing that would develop here that would persuade you to support the nuclear freeze.

Mr. EMERY. We threw that idea out as an inadequate response because of current instabilities that would be frozen into a period of time that we consider to be a very, very dangerous result, instabilities that can encourage one side or the other to take some precipitous action that could trigger the very holocaust that we are seeking to avoid. We think the best way to solve that problem is not simply to freeze, which will reward the Soviets for the years of military buildup and freeze in instabilities and asymmetries that are not in our national interest and not in the interest of world peace, but to move beyond that and in fact the Soviets, themselves, in statements leading up to their initial participation in the START agreements are already talking about levels of nuclear forces that were somewhat less than those that had been negotiated in SALT II. So we have already transcended the question of current levels and we have both sides talking in principle of reductions below levels that currently are in existence. And I can't conceive of any person concerned about nuclear war who would rather trade the problems of today and keep them and pass up an opportunity to negotiate substantial reductions, no matter what the final formula looks like. It makes absolutely no sense to me.

Mr. **Wagner**. Senator, could I address that point because as I have been sitting here I have been hearing us sounding inconsistent in the way that you just described, that on one hand we say we are concerned about the phenomenon, but on the other hand we say that we are not changing our policy.

Let me try to clarify that. I think what we have been saying is that our most fundamental policies—the policy of deterrence, the policy of seeking reductions in force levels in a way that maintains stable deterrence—those aren't changed. And, in fact, if they are changed by this, it's only to add emphasis and urgency to them.

The kinds of things I can imagine might change are at sort of the next level of detail down in policy. At the risk of getting into an area that we simply have not thought through because it's hard to think through, let me pose a kind of speculative example for you.

Suppose that there were a sharp threshold in some scenarios for the onset of nuclear winter. An attacker might be tempted to in effect use up the quota in his first strike of allowable smoke in the atmosphere and the prospect of going over the thresholds would inhibit the response which we would depend on to deter. I could imagine that. I doubt that it will turn out that there will be a sharp threshold. I think it would be terribly unfortunate if there were, because it would introduce that kind of a new instability into our thinking about stable deterrence and crisis stability that I think would be a terrible thing.

Senator **Proxmire**. That raises a question that you could have a situation where people might just target their force or whatever to create a situation in the world where whoever proceeded any further would trigger a nuclear winter.

Mr. **Wagner**. As I say, I have been sitting here all morning wondering whether or not to introduce that thought. I think it's a tremendously speculative thing. I suspect it will not turn our that way. I use it as an example of the level at which these kinds of things may, in fact, influence our policy. I think if it turned out that way, it could have serious implications. We can't say what our response would be today. We would have to think it through more carefully. It is those kinds of things that the policy studies and the technical studies and the interrelation between them we will have to address.

Senator **Proxmire**. Thank you very, very much. Both of you gentleman have been—all of you gentlemen have been extremely helpful and responsive and we greatly appreciate the record that you have made and it's a good record.

This afternoon we will convene at 3 o'clock in the same room right here to hear Sidney Winter, an economist expert from Yale University, who will discuss the economic consequences of a nuclear winter, and David McLouglin, who is Assistant Associate Director for State and Local Programs at FEMA. FEMA has been a particular target in these hearings and we will hear about them this afternoon.

The subcommittee will stand in recess until 3 o'clock.

[Whereupon, at 12:25 p.m., the subcommittee recessed, to reconvene at 3 p.m., the same day.]

AFTERNOON SESSION

OPENING STATEMENT OF SENATOR PROXMIRE, VICE CHAIRMAN

Senator **Proxmire**. The meeting will come to order.

We are delighted to have the two eminent witnesses before us this afternoon.

Before we go on, I have a little statement to make primarily, however, on civil defense because it's an issue that we've worked on in the Joint Economic Committee before and on the Committee on Defense Production. I wanted to give Mr. McLoughlin my views and Mr. Winter, too.

My thinking on this has undergone some modification in recent years. In 1977 and 1978 the Joint Committee on Defense Production conducted the most comprehensive review of civil defense activities to that date. The committee found that a nationwide civil defense effort to protect lives in the aftermath of a medium or large nuclear exchange was nearly, if not totally, impossible to achieve. The reason was the inability to supply survivors with food, water and medical assistance when the Nation's transportation, power, and communication system had been destroyed.

Under the Carter administration the National Security Council also examined this question. They found that a nationwide civil defense system composed of shelters and limited foodstuffs designed to save a fraction of the population during a nuclear war would cost a minimum of $20 billion in constant dollars and more like $40 billion.

This would not include the enormous operating costs involved in the resupply of food and water to shelters, the guarding of shelters during peace time of any guard against radiation. Protection would simply be for blast affects and perhaps a week or two of food.

The picture for protection of our entire population remains the same today, though, some of the concepts have changed. We are now looking at crises relocation, the moving of millions of people out of the major cities prior to an attack and the so-called host counties.

Of course, there are many problems also associated with this concept: Can the host areas handle the influx of millions of people, who will keep order, how will food be distributed, will host area residents welcome the millions from the cities.

In fact, many counties designated as host areas in Wisconsin have vigorously protested this concept. Our Governor, who is a very, very able man, has indicated that he simply will do nothing at all to support the efforts in the State to provide civil defense for nuclear war. He thinks that nuclear war would be such a disaster that you can forget it as far as nuclear defense is concerned.

But the question remains, is it not the responsibility of the Federal Government to protect its people? The answer is, yes. In my opinion, some protection should be considered for situations that might involve the accidental explosion of a nuclear device, the use of a nuclear device by terrorists, or even the most cataclysmic kind of nuclear development, which I'm going to come to in a minute.

I'm not talking about a $40 billion shelter and food-stocking program, but quick reaction forces designed to move, decontaminate the area, provide whatever medical assistance could be provided, which admittedly would be extremely rudimentary and limited. Generally provide the assistance the affected population will need.

Such a plan is not now in existence, but is badly needed in my opinion. A few years ago I wrote various Federal agencies to ask if the United States had such a plan for a bomb going off somewhere else in the world. The answer basically was, no, we have no plan for our country.

Now, the most comprehensive—these estimates are all so general—the most comprehensive estimate I've seen of the casualties in a nuclear war were made by the World Health Organization, which estimated 1 billion people killed in the initial fact and another billion dying in the aftermath of the nuclear war, leaving about half the people of the world.

I was surprised, shocked at a terrible event that occurred in our State about 1 month ago. A little town called Barneveld. It was hit by a tornado. Just a devastating tornado. A town of 571 people. It struck at 1 o'clock in the morning, the middle of the night. It absolutely flattened more than half the houses. I mean flattened. Just nothing left. Another 25 percent were partially damaged and mostly severely damaged. Every single business in the village was flattened. Completely. There are five churches; all five churches were disintegrated. Nothing left. Blown away.

The surprising thing to me was that in this village of 571 people only 9 were killed. People talk about cockroaches being all that's left.

People are very, very tough. And I see no estimates that would assume that even a cataclysm would wipe out all 232 million Americans. If only 10 percent were left that would be 23 million people, and if it costs us $20 billion, or $40 billion, or whatever to provide, and I think it would provide less to have the most sensible kind of a program, but if it would cost that much it might well be worth it.

Mr. Sagan reminded us in a most dramatic statement that if the human species perishes then none of our lives have any meaning. So, I think that we have an obligation to do what we can. As I indicated I'm not at all satisfied at present with anything I've seen about the civil defense program, although it serves the very useful purpose for disasters, but it wouldn't do anything very significant, substantial for a nuclear disaster. But it seems to me we ought to be thinking about that. Even as I say, if there are only very, very few, a pitiful few, in appalling conditions, who are left, I think we have an obligation to do what we can.

Well, gentlemen, we're delighted to have you here. Mr. Winter is the eminent economist, an expert who has done a lot of work on this. Thought about it deeply. Yale University, I'm proud and happy to say. Graduated from there 46 years ago, and, Mr. McLoughlin, we're happy to have you here, too.

Mr. Winter, if you would go ahead first.

STATEMENT OF SIDNEY G. WINTER, PROFESSOR OF ECONOMICS AND MANAGEMENT, YALE UNIVERSITY

Mr. WINTER. Thank you, Senator Proxmire.

Senator, it seems to me that a ritual invocation should precede every discussion of nuclear war, an affirmation of humility before the awesomeness of the subject; a dedication to the task of advancing understanding, and mutual assurances of respect for each other's opinions in the event that disagreement should arise. Consider such an invocation read. I'm not going to try to cast it in a more poetic form.

I will also not try to cover in detail my entire prepared statement, which is lengthy. Rather I want to try to touch upon the high points.

I understand that I've been asked to appear here primarily in my capacity as an expert on the economic consequences of nuclear war. I'm an expert on this subject in the very limited sense that many years ago I devoted a year or two of my working life to trying to understand this subject, and have had some peripheral contact with it since then.

However, I appear here also in two other roles: As a citizen of the United States and as an inhabitant of planet Earth. In these capacities I feel entitled to be more emphatic in my predictions and judgments than I can justify on the basis of my specialized knowledge alone.

In these remarks this afternoon I want to be brief and clear about where I come down on some of the central questions and make only brief references to the more detailed analysis contained in my prepared statement. I would like to make seven points, with particular emphasis on the first two.

First, under present and foreseeable future circumstances the deliberate initiation of nuclear hostilities by either of the super powers against the other would very likely produce a nuclear war that is large scale and uncontrolled, specifically, in the sense that nuclear weapons aggregating several hundred to a few thousand megatons in explosive yield would be detonated over U.S. territory and a substantial portion of the total would be over densely populated areas.

Second, under present and foreseeable future circumstances, a large scale and uncontrolled nuclear war with the Soviet Union would call seriously into question the survival of the United States as a national entity. By a failure to survive as a national entity, I mean an outcome such that the population surviving 5 years after the war would comprise less than 10 percent of the preattack population. These survivors, if any, would be organized politically and economically in numerous small fragments of the previous society, ranging in size from predatory gangs to regional organizations, involving a few of the former States.

In my prepared statement I go into some detail about the reasons for this conclusion about the prospects for national survival in case of nuclear war. I note that whereas it is very simple to reach this conclusion, if the nuclear winter study is essentially correct, it should not be thought that the situation is a great deal different so far as the United States is concerned, at least, even in the total absence of nuclear winter. Rather, the vulnerability of the economy and of the food supply system, in particular, are such as to call national survival into question at attack levels involving a few hundred weapons on urban industrial targets.

Obviously climatological disturbances much smaller than those described in the nuclear winter study would greatly complicate the problem of national survival. I should emphasize, however, that this subject has been very inadequately studied. It should be studied more carefully, particularly in the defense community.

My third point is that in the circumstances of the present and foreseeable future, no significant measures have been or will be taken to protect the U.S. population from any of the effects of nuclear war. Serious preparedness programs could surely reduce short-term casualties from blast, fire, and radiation. Whether the result would be markedly increased population survival 5 years after the attack is much more difficult to say and perhaps impossible to establish with high confidence, regardless of the extent of preparedness measures.

If post-war climatological and ecological conditions are accurately described in the TTAPS study and its companion article, it seems quite likely that long-term survival would not be enhanced.

In any case, consistent with what you have stated, Senator, serious preparedness measures would involve expenditure rates 10 to 100 times larger than recent actual expenditures on civil defense, leading to a major change in the tone of our national life. There appears to be no prospect that such programs will be undertaken.

Fourth, the belief that the United States needs a so-called nuclear-war-fighting capability appears to be based in large part on an underestimate of the threat to national survival represented by large-scale nuclear conflict, and perhaps, incidentally, on a mistaken appraisal of the political acceptability of civil defense in the United States.

Fifth, although apocalyptic visions of the implications of nuclear war have been a feature of popular discussion since the dawn of the nuclear age and although numerous proposals have been made from time to time considering the possible mechanisms for such an extreme result, it appears to me that the nuclear winter study is quite unprecedented in the credibility and explicitness of its apocalyptic speculations. Unless further investigation of the nuclear winter hypothesis convincingly disposes of these speculations, the TTAPS study must be considered to inaugurate a new era in the discussion of nuclear armaments.

In this new era the force of the moral critique of nuclear weapons, based on concerns for the fate of the human species and of other life on the planet as a whole, will be much more widely acknowledged, even in circles where such concerns were formerly dismissed as naive and uninformed.

Sixth, a number of important policy issues, including the civil defense question, appear in a different light if we recognize that the deliberate initiation of nuclear war by one of the superpowers is not the only circumstance in which nuclear weapons might be detonated over U.S. territory.

A variety of other contingencies are possible, implying a wide spectrum of possible damage levels. In addition to accidental or unauthorized initiation between the superpowers, these include terrorist attacks, accidental detonations of U.S. weapons, and attacks by national adversaries other than the Soviet Union.

Although these scenarios may be individually implausible, I believe that in the aggregate they are more likely than deliberately initiated war between the superpowers. This may be particularly true of the more remote future when we may hope that the tensions between the Soviet Union and the United States will be reduced, in part because of the shared danger from these very contingencies.

The reality of these contingencies constitutes, as you have suggested, Senator, a different and stronger case for higher levels of civil preparedness than the prospect of large-scale conflict between the superpowers. This reality also indicates that the United States may well need a nuclear-war-stopping capability of which one important component is the same sort of survivable command control, communications and intelligence capabilities that are required for a nuclear-war-fighting capability.

Seventh, civil defense and other preparedness measures should not be rationalized on the grounds of their relevance to crisis bargaining or to the United States-Soviet Union strategic balance in general, nor should they be designed with those considerations in view.

This is so for two very powerful reasons. The first is that whatever the effectiveness of such programs in the context of large-scale nuclear war, it is a category of activity in which the Soviet Union has done a good deal more than the United States. This same condition is likely to persist for years into the future barring very radical changes in U.S. policy.

Under these circumstances, to concede the strategic importance of civil defense and thus lend credibility to the notion that the Soviet Union has successfully bought some sort of strategic bargaining advantages by its investment in civil defense is itself a reckless dissipation of our own bargaining power, a course of action not to be recommended even if the Soviet programs deserve the credibility that is freely granted to them.

But, of course, the second powerful reason referred to is that the Soviet programs most likely do not deserve that credibility. Those programs are unlikely to assure long-term national survival for the Soviet Union regardless of how they might perform during the war and its immediate aftermath.

This is the probable outlook, regardless of the prospect of climatological catastrophe, but, of course, becomes overwhelmingly plain if that prospect is realistic.

In conclusion, I would like to comment briefly on implications of the nuclear winter hypothesis for nuclear strategy and arms control. If the hypothesis should emerge essentially intact from the intense scientific scrutiny that it will surely receive, then the most important question by far is whether the political and military leaderships of the United States and the Soviet Union will acknowledge this reality and accord it appropriate weight as a determinant of their behavior. If they do so, the world will promptly become a great deal safer by virtue of the drastically changed incentives for the initiative of nuclear war by preemptive strike in the context of a severe crisis.

Of particular importance here is the fact that the society of the attacking nation would be destroyed by the effects of its own weapons, regardless of any retaliation. The world might also become safer ultimately through agreements on the reduction of strategic arsenals.

On the other hand, if leadership groups are not persuaded, both of the reality of nuclear winter and of its acceptance as a reality by the other side, neither the improvement in crisis stability nor the improved prospects for arms control are likely to materialize. Therefore, the highest priority for the near future is to subject the nuclear winter hypothesis to the most careful scrutiny and discussion, in such a manner as to maximize the chance that the ultimate conclusions will be accepted where it counts.

Thank you, that concludes my statement.

[The prepared statement of Mr. Winter follows:]

PREPARED STATEMENT OF SIDNEY G. WINTER

ECONOMIC CONSEQUENCES OF NUCLEAR WAR

The topic of these hearings is one that severely challenges the human capacity for rational discourse.

Because the human values at stake are so enormous, intense emotional reaction to the subject matter is in one sense quite appropriate, and in any case difficult to avoid.

Because of the limited power of our imaginations, we are blessedly unable to conceive of the scope of the suffering that a nuclear war would entail. We use numbers to compare one horrendous prospect with another, or with the catastophes of the past, but we cannot begin to comprehend what these numbers mean in human terms. Yet if we allow ourselves to become too resigned to the limited reach of our imaginations or too immersed in the abstract statistical view of the horror, we may lapse into some form of psychological denial of the reality of our peril, and thus undercut our own motivation to deal with the threat.

Because the consequences of a large scale nuclear war extend far beyond the range of experience in so many complexly interrelated dimensions, in the subject matters of all of the sciences, the power of the methods of science to illuminate those consequences is fundamentally limited. Few conclusions are incontestible; consensus is hard to achieve; the verdicts rendered often rest heavily on unstated assumptions about where the burden of proof lies.

In the face of these great obstacles to rational discussion, we have no moral or practical choice but to carry on as best we can. It seems to me that a ritual invocation should precede every discussion of nuclear war; an affirmation of humility before the awesomeness of subject, a dedication to the task of advancing understanding, and mutual assurances of respect for each other's opinions in the event that disagreements arise. Consider such an invocation read; I will not attempt to cast it in more poetic form.

I understand that I have been asked to appear here primarily in my capacity as an expert on the economic consequences of nuclear war. I am an "expert" in the very limited sense that many years ago I devoted a year of two of my working life to trying to understand that subject, and have had peripheral contact with it since then. However, I appear here also in two other roles, as a citizen of the United States, and as an inhabitant of planet Earth. In these capacities, I feel entitled to be more emphatic in my predictions and policy judgments than I can justify on the basis of my specialized knowledge alone. To provide a context for the more detailed discussion, and to avoid any possible misunderstanding about where I "come down" on some questions of cental importance, I would like to express some of these predictions and judgments at the outset.

1) Under present and foreseeable future circumstances, the deliberate initiation of nuclear hostilities by either of the two superpowers against the other would very likely produce a nuclear war that is large scale and uncontrolled, specifically in the sense that nuclear weapons aggregating several hundred to a few

thousand megatons in explosive yield would be detonated over U.S. territory, and a substantial portion of the total would be over densely populated areas.

2) Under present and foreseeable future circumstances, a large scale and uncontrolled nuclear war with the Soviet Union would call seriously into question the survival of the United States as a national entity. A "failure to survive as a national entity" may be defined as an outcome such that the population surviving five years after the war would comprise less than ten per cent of the preattack population, and these survivors (if any) would be organized politically and economically in numerous small fragments of the previous society, ranging in size from predatory gangs to regional organizations involving a few of the former states. In the absence of the sort of climatrological catastrophe described in TTAPS, (Turco, et.al, 1983), a reasonable assessment of the likelihood of a failure to survive as a national entity would be "quite possible" for the smaller attack weights and "quite probable" for the larger attack weights. On the other hand, if TTAPS calculations are indicative of the climatological consequences of nuclear war, failure to survive as a national entity is highly probable to certain for any large scale nuclear war and quite possible even for very limited nuclear exchanges.

3) The circumstances of the present and foreseeable future include the fact that no significant measures have been undertaken to protect the U.S. population from any of the effects of nuclear war. Serious preparedness programs could greatly

reduce short term casualties from blast, fire and radiation. Whether the result would be markedly increased population survival five years after the attack is much more difficult to say, and perhaps impossible to establish with high confidence regardless of the extent of preparedness measures. If postwar climatological and ecological conditions are accurately described in the TTAPS study and its companion article, it seems quite likely that long term survival would not be enhanced. In any case, "serious" preparedness measures would involve expenditure rates ten to a hundred times larger than recent actual expenditures on civil defense, leading to a major change in the tone of our national life, and there appears to be no prospect that such programs will be undertaken.

4) The belief that the United States needs a "nuclear war fighting capability" appears to be based in large part on an underestimate of the threat to national survival represented by large scale nuclear conflict, and perhaps incidentally on a mistaken appraisal of the political acceptability of civil defense in the United States. The impression that unrealistic images of nuclear war conditions are basically involved is much strengthened by official references to planning for "mobilization" under nuclear war conditions, a notion which is probably impractical under almost all conditions of nuclear conflict, regardless of the validity of the TTAPS analysis. However, if the TTAPS conclusions are essentially correct, the incompatibility between nuclear war fighting concepts and the national interest becomes radical. Sagan (1984) notes that, because a counterforce first strike would probably exceed the

threshold for inducing climatic catastrophe, the decision to launch such a strike would be "tantamount to national suicide for the aggressor -- even if the attacked nation does not lift a finger to retaliate..." (p. 276). The very act of achieving a maximum military success, disarming the adversary, would be self-destructive. (See also H.A. Simon, 1984.)

5) In commenting on the biological and ecological implications of the TTAPS calculations, Ehrlich et. al. (1983) write as follows "... the combined intermediate and long-term effects of nuclear war suggest that eventually there might be no survivors in the Northern Hemisphere," and even "... the possibility of the extinction of Homo sapiens cannot be excluded." Although apocalyptic visions of the implications of nuclear war have been a feature of popular discussion since the dawn of the nuclear age, and although numerous proposals have been advanced from time to time adducing possible mechanisms for such an extreme result, it appears to me that the TTAPS analysis is quite unprecedented in the credibility and explicitness of its apocalyptic speculations. Unless further investigation of the nuclear winter hypothesis convincingly disposes of these speculations, the TTAPS study must be considered to inaugurate a new era in the discussion of nuclear armaments. In this era the force of the moral critique of nuclear weapons, based on concerns for the fate of the human species and other life on the planet as a whole, will be much more widely acknowledged, even in circles where such concerns were formerly dismissed as naive and uninformed.

6) The deliberate initiation of nuclear war by one of the superpowers is not the only circumstance in which nuclear weapons might be detonated over U.S. territory. A variety of other continengies are possible, implying a wide spectrum of possible damage levels. In addition to accidental or unauthorized initiation between the superpowers, these include terrorist attacks, accidental detonations of U.S. weapons, and attacks by national adversaries other than the Soviet Union. Although these scenarios may be individually implausible, I believe that in the aggregate they are more likely than deliberately initiated war between the superpowers.

This may be particularly true of the more remote future, when tensions between the Soviet Union and the United States may be reduced, in part because of the shared danger from these other contingencies. The reality of these contingencies constitutes a different, and stronger, case for higher levels of civil preparedness than the prospect of large scale conflict between the United States and the Soviet Union. This reality also indicates that the United States may well need a "nuclear war stopping capability", of which one important component is the same sort of survivable command, control, communications and intelligence capabilities that are required for a "nuclear war fighting capability."

7) Civil defense and other emergency preparedness measures should not be rationalized on the grounds of their relevance to crisis bargaining or to the U.S. - S.U. strategic balance in general, nor should they be designed with those considerations in view. This is so for two very powerful reasons. The

first is that, whatever the effectiveness of such programs in the context of large scale nuclear war, it is a category of activity in which the Soviet Union has done a good deal more than the United States. This same condition is likely to persist for years into the future, barring much more radical changes in U.S. policy than now seem likely. Under these circumstances, to concede the strategic importance of civil defense, and thus lend credibility to the notion that the Soviet Union has successfully bought strategic bargaining advantages by its investment in civil defense is itself a reckless dissipation of our own bargaining power -- a course of action not to be recommended even if the Soviet programs deserve the credibility freely granted to them. But of course, the second reason referred to is that the Soviet programs most likely do not deserve that credibility. Those programs are unlikely to assure long term national survival for the Soviet Union, regardless of how they might perform during the war and its immediate aftermath. This is the probable outlook regardless of the prospect of climatological catastrophe, but of course becomes overwhelmingly plain if that prospect is realistic.

Economic Consequences of Nuclear War (No Nuclear Winter)

I turn now to more detailed discussion of the economic consequences of nuclear war. Because I believe that official planning relating to this topic has long reflected inadequate understanding founded on drastically inadequate research, I will begin with the basics. In particular, I will set aside for the moment the specific economic implications of the nuclear winter hypothesis.

The central question in the analysis of economic and other long term effects is the fate of that portion of the population that would survive the immediate and short term effects of a nuclear war; for concreteness, consider the portion of the population that survives at least thirty days after the start of the war, assuming termination of the war within that interval. Depending on the weight and pattern of the attack, estimates of the percentage that these survivors of the blast, fire and prompt and fallout radiation effects represent of the preattack population range widely -- say, from 5 to 90 per cent. In no case is the percentage estimated to be zero, and certainly in the world as a whole the surviving percentage would be large. As TTAPS say, "Most of the world's population could probably survive the initial nuclear exchange and would inherit the postwar environment." (p. 1283). But the question is how hostile this environment is, and whether the early survivors would still be alive two years or five years later.

It would probably be universally conceded that the postwar envivronment would be very hostile relative to the preattack environment, and that mortality among the early survivors would substantially exceed the levels that were normal preattack. If 80 per cent of the early survivors could be expected to be alive five years later, it might be reasonable to say that the levels of the immediate and short term fatalities were adequately indicative of the "consequences" of the war. One certainly would not be willing to say that if only 20 per cent of the early survivors were still alive after five years. And it is certainly possible to conceive of situations in which early survival would be not at all indicative of long term survival -- consider the case of a population protected from massive attack by shelters stocked for a thirty day stay, but lacking in any preparations or means to obtain the necessities of life after that period.

The contemporary economy of the United States is a system of extraordinary effectiveness and extraordinary complexity. It is a familiar fact that the principles by which this system functions, under normal peacetime conditions, are not perfectly understood -- at least, not so perfectly as to make accurate prediction possible. The vulnerabilities of this complex system to the enormous shock of nuclear war are undoubtedly very numerous, and some of them may be subtle. There are great uncertainties about a number of key questions, beginning with questions about the psychological state of the survivors and their ability and willingness to work, and extending to questions of the survival and reconstruction of basic economic and political institutions. The technological and organizational knowledge required for effective economic adaptation to the postattack environment is not "on tap" or "on file" in the existing economy; it would have to be painfully sought under the stressful circumstances of the actual situation. I obviously cannot deal with all of these issues here. I choose to focus on one that I believe to be the most critical of the relatively analyzable issues relating to the prospects for survival of the United States as a national entity.

To survive in the long term, the early survivors must have food, among other things. Setting aside the possibility of massive food imports to a country that was a large food exporter in the prewar world, the survivors must be able to produce food adequate to their needs, when the inventory of food inherited from the prewar world runs out. At present, the food needs of the U.S. population are met (with major exports left over) by a system of production that involves an elaborate division of labor. This system involves a low level of labor input on the farm and a high use of mechanization. In the short term, mechanized agriculture is driven by gasoline and diesel fuels derived from petroleum. To continue this basic system in a post nuclear war environment, minimum requirements include some capacity to produce and refine petroleum; transportation of the fuels to the farms; labor, seed and other inputs on the farm; an transportation, processing and distribution of the food to the surviving population.

I do not believe that there is a realistic alternative to this form of organization that is consistent with the survival of the United States as a national entity. In other words, I do not believe that it is realistic to believe that most of the survivors could support themselves by recourse to agricultural methods of a centry ago, given the obstacles to be overcome in the form of inappropriate initial location of the population and the deficiencies of knowledge and skills,appropriate tools, and physical strength, plus inadequate living accommodations in agricultural areas, and the probable adversities of the postattack agricultural environment, particularly given the necessity of overcoming these obstacles in a relatively short space of time. It is a question of restoring the system based on mechanized agriculture, with its dependence on petroleum refining and transportation, or of reverting to much more primitive methods within isolated pockets of population survival. (This may be a point of disagreement with Ehrlich, et. al. (1983), who seem to give some credence to the notion of temporary reversion to a more primitive agriculture -- but perhaps it is isolated pockets of survival that they have in mind.)

Although the problem of timely restoration of agricultural production is a key issue in the analysis of the consequences of nuclear war, it has not been adequately studied. So far as I am aware, there does not exist any study that provides an affirmative basis for the belief that this problem would be manageable under any plausible large-scale attack contingency in the near future. Such a study would be one that dealt (at a minimum) with two key features of the problem posed, (i) the existence of deadlines arising from the fact that the population must be fed while the effort to restore production is made, (ii) the fact that damage to the transportation system means that the initial postattack economy is a fragmented economy, in which statistics on national aggregates of resource survival are meaningless. Of course there are possible bases for belief that the problem is manageable other than the sort of study described. These cover a spectrum ranging from sophisticated, informed judgment based on full understanding of the problem and exposure to the available research to an empty bravado that avoids a square confrontation with the issue.

While existing knowledge cannot support even a modest burden of proof that the food supply problem is manageable, it definitely provides grounds for anticipating major difficulties. To begin with, some key elements of the system, including petroleum refineries, petroleum ports and major transportation facilities are not particularly numerous. Three hundred relatively small nuclear weapons, deliberately targeted on these elements of the economy, will produce very low survival levels in these resource categories. Further, many of these targets are located in or near urban areas. This implies on the one hand that attacks on the more specific economic targets would incidentally cause extreme disruption and large population and economic losses; on the other hand, attacks on urban areas in general, or on military targets in or near such areas, would incidentally cause large damage to petroleum refineries and transportation. Regarding the latter type of attack, although aggregate survival of refining capacity would probably be adequate for agricultural and transportation requirements, the fragmentation of the economy might render aggregate survival irrelevant.

Agriculture itself presents a very different type of vulnerability problem. Immediate casualties and destruction from blast and fire would be relatively small, but in the intermediate term the farm population and farm animals are vulnerable to fallout radiation. In the longer term, agricultural recovery would be inhibited because of the losses incurred in the farm population, soil and water contamination and perhaps because of climatological and ecological disturbances. Absent the nuclear winter effect, the impact of nuclear war on agriculture depends on attack weight and characteristics in a very different way than does the damage to urban target systems. Since fallout is the central problem, the key parameters are total yield, fission fraction, number of ground bursts, location of targets relative to agricultural areas, and time of year. In general, the implication is that it is collateral damage from large counterforce attacks that poses the largest threat to U.S. agriculture. As I explain in the following section, this conclusion is radically altered if the nuclear winter threat is real.

In my 1963 RAND study, I concluded a more detailed investigation of some of the considerations mentioned above by setting forth my judgments on how the long term economic outcome might depend on attack weights and characteristics. I think it is useful to reproduce here a central portion of that concluding statement. I will then comment on how those conclusions would be modified by changes in the situation other than the development of the nuclear winter hypothesis. In the following section, I consider the implications of nuclear winter. (Statements in brackets are insertions for clarification of the 1963 text.)

"Total Weight 1000 to 4000 Megatons, 500 Megatons or Less on Nonmilitary Targets

"If all or nearly all targets were attacked with air burst weapons, the prospects for viability [that is, for the population to support itself in the long term] after attacks in this range would be about as good as in the previous case [failure would be unlikely]. The effect on the nation's industrial plant would be essentially the same, and would be unlikely to pose critical problems. For plausible geographical distributions of the attack, a significant fraction of the country's area might be burned over, but the prospects for postattack agricultural production should not be seriously affected in the short run. If the attacker used surface bursts against most targets, the effects of fallout might create serious obstacles to viability. First, an attacker who used 500 megatons against nonmilitary targets and sought to maximize "bonus" damage from a 3500 megaton attack on military targets could kill a large fraction of the population -- 60 per cent of more -- if no fallout shelters were available. Total casualties might approach 80 per cent of the population. Such a low level of population survival would by itself make the achievement of viability very difficult.[1] Second, a substantial intensification of the pest problem in agriculture would be a possible consequence of the ecological imbalances produced by the period of high radiation levels. The economy would be much less capable of dealing with this problem than it was preattack (even if the attacker did not devote special attention to the pesticides industry), unless special preparations were made. No firm prediction about the seriousness of the resulting situation is justified, but the possibility of a major pest problem introduces some uncertainty into the picture.

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[1] Important skill groups in the labor force would be totally wiped out, and the resulting problems at the strictly organizational level would be enormous.

"Certain preparations would have to be made in order to give the economy a "medium confidence" capability for viability after the worst of the attacks in this range. First, the population would have to be moderately well protected against fallout -- the equivalent of protection in an ordinary basement, with windows sandbagged, and stocked for a two week stay. Second, preparations would have to be made to assure that production of pesticides could quickly surpass preattack levels, and to guarantee a capability for investigating, analyzing, and attacking pest problems as they appeared. Third, preparations would have to be made for quick restoration of the network industries, [transportation and communications, electric power] and the alleviation of specific bottlenecks elsewhere. The cost of preparedness program of this sort might be expected to be in the one to ten billion dollar range.

"Total Weight 1000 to 4000 Megatons, 750 to 2000 Megatons on Nonmilitary Targets

" It is believed that this is the range where the loss of industrial capacity would create serious to insuperable obstacles to viability, unless extensive preattack preparations were made. Much would depend on whether the attacker did or did not attempt to maximize the economic difficulties created by the nonmilitary portion of the attack; but if not, the change from the preceding case would be that an additional 15 to 20 per cent of the population would be killed, the balance between surviving population and resources would be less favorable, and there would be more industrial categories in which capacity was reduced close to zero. Good to excellent[1] fallout shelter would be required to keep casualties below 60 per cent of the population. The overall balance between industrial capacity and population would not be at an obviously disastrous level, even if population survival were well above 50 per cent. It might be possible to achieve viability if the effects on the natural environment did not create a highly unstable ecological situation and preparations were made for dealing with these problems, and if the numerous specific bottlenecks could be alleviated. The last might be accomplished through foreign trade, except that it would be difficult to produce anything for export; and, in addition, a very large fraction of the country's port capacity would centainly be destroyed. Success in achieving viability, without the benefit of more extensive preparations than have thus far been considered, seems quite unlikely.

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[1] By "excellent" fallout shelter is meant something of the sort investigated by the U.S. Naval Radiological Defense Laboratory, with a radiation attenuation factor of 100, resistant to 35 psi of blast overpressure, and affording protection against firestorm as well. (See the testimony of W.E. Strope, Civil Defense, 1961, pp. 233-257.)

"If the attacker did choose to attempt to maximize economic difficulties, success would be even less probable. How severely the economy could be crippled by an attack of 2000 megatons in at most 400 weapons is not considered in detail. However, it seems probable that such an attack could destroy 100 per cent of the port capacity and petroleum refineries, incidentally destroying perhaps 40 to 50 per cent of other industrial capacity in general, with some weapons left over. Those additional weapons might well reduce survival in additional industrial categories to close to zero. For the attack pattern that would produce these results, about two-thirds of the population might survive, if excellent fallout shelter were available. Although the food stockpile would last for two or three years, it seems very doubtful that this period would suffice for piecing together the economy after such an attack.

"The over-all balance between resources and population would not be critical, and therefore the preparations required to make viability possible after attacks in this range (in addition to those already mentioned) would involve a relatively selective program of stockpiling, construction of underground factories, and so on, in order to forestall the appearance of certain bottlenecks, plus more elaborate preparations to restore transportation, communications, and other services not readily stockpiled or moved underground, plus general preparations to facilitate the repair or partial salvaging of damaged capacity. It is probable that an adequate program of this sort might cost in the low tens of billions of dollars. Of course, if effects on the natural environment turned out to have particularly serious consequences, viability might be unattainable in spite of this degree of preparation." (Winter, 1963, pp. 154-157).

My primary purpose in presenting these two-decade old statements here is to emphasize that the concept of broad "thresholds", beyond which the survivability of nuclear war becomes very dubious, has a basis in considerations other than the prospect of nuclear winter and associated ecological disturbances. It should also be emphasized that the apparent levels of these thresholds -- crudely estimated on the basis of admittedly very imperfect understanding -- are well within the level of the strategic arsenal of the potential adversary, and generally correspond to what defense analysts would consider "medium intensity" nuclear war.

Although it is not possible for me to present a genuine updating of my 1963 study, I should note two major differences between the present situation and the one that appeared to be unfolding twenty years ago. The study was done before the advent of MIRVing, when it appeared that individual warheads would typically be in the multi-megaton range. In fact, most of my actual calculations assumed individual warheads of 10 megaton yield.

The much smaller size, and greater numbers, of warheads in contemporary arsenals makes a radical difference in the implications of given total yields on urban and industrial targets, given that it is primarily blast effects that are at issue. A crude adjustment for this change (based on "equivalent megatonnage" with a change in typical warhead size from 10 MT to 500 KT) translates the 500 MT figure into 185 MT, 750 MT into 275 MT, and the 2000 MT figure into 735 MT. A substantial further reduction in these numbers might well appropriate, given that the argument relates essentially to the destruction of a few hundred specific targets.

The total attack weights mentioned in the conclusion of the 1963 study are relevant primarily because of the extent of the fallout hazard they represent, assuming that the non-urban portion would typically involve a major componet of counterforce attacks involving ground bursts over missile sites. I am not able to say how the change in typical warhead sizes affects the fallout hazard implicit in a given total attack weight, but I suspect that any systematic difference under this heading is much less consequential than the difference in area covered by blast effects.

The second major difference between 1963 and the present is that in 1963 the United States had in place, albeit quite unintentionally, a major component of a meaningful, multi-billion dollar civil defense program. Surplus grains placed in widely dispersed storage under federal price support programs were a major factor in total food stocks, and the total stock contained the caloric equivalent of minimum nutritional support for the entire population for a period of about two years. Proposals for modest civil defense programs exploiting this resource and opportunities for relatively inexpensive fallout protection seemed at the time to hold considerable promise. Today we live, nationally and globally, much closer to the margin so far as food supplies are concerned. At seasonal lows, food stocks the U.S. sometimes fall to the neighborhood of two months supply.

Implications of Nuclear Winter

I now consider how the prospects for population survival are affected if the climatological effects of nuclear war are accurately characterized by the TTAPS study. My remarks in this connection are not based on a systematic study of my own but simply on some sustained reflection on the relationship between the TTAPS analysis and previous understanding of the economic consequences of nuclear war. TTAPS emphasize that their general conclusions are quite "robust" with respect to attack weight, provided that at least several hundred weapons are detonated over urban areas. Accordingly, and considering that my comments are impressionistic in any case, I will not attempt to differentiate my conclusions according to the distinctions among the different cases considered by TTAPS.

For those fortunate enough to live in areas not severely affected by blast, fire and prompt radiation, a period of severe to very severe cold, of some months duration, would obviously pose a major survival hazard. This hazard would be additional to, but in some ways comparable to, the hazard from radioactive fallout. Like fallout, it would threaten large areas and it would quite clearly be fatal to a population that was both unprepared and unresponsive to the hazard as it emerged; also, it would present a direct threat to agriculture which would be very difficult to mitigate. However, it differs importantly from fallout in that these consequences would be brought about by the same weapons that destroyed cities, whereas much of the fallout threat is associated with counterforce attacks. As a result, the total weight of an attack becomes much less relevant to the assessment of its consequences.

There is perhaps another important difference in that the problem of surviving a period of intense cold is undoubtedly much better understood by people in general than is the problem of surviving radioactive fallout. However, the exacerbation of the problem by darkness and the interruptions of utility services and fuel supplies over large areas certainly suggest that the task of survival would present a formidable challenge.

As in the case of most other effects of nuclear war, it is possible to conceive of preparedness measures that under some circumstances might greatly enhance the survival prospects of much of the population. And, as in the case of other effects, such measures would be (i) probably ineffective in areas subject to the most severe hazard (in this case, the areas of greatest cooling), (ii) extremely expensive, (iii) of dubious value if the war involves an exchange of a large fraction of the existing strategic arsenal, (iv) of dubious value in any case unless all of the other threats to long term survival could also be coped with.

Setting aside the problem of surviving the cold _per se_, consider the implications for agriculture. It seems clear that the prospect of a nuclear winter entails the entire loss of at least one growing season. This, in my view, only underscores a point already plain from consideration of the other vulnerabilities of agriculture: there is very little prospect for long term survival of a substantial portion of the population unless surviving food stocks are adequate to support the surviving population for a least one year without additional production. Generalized disruption of the economy, together with the direct impact of radioactive fallout on the farm population, standing crops, livestock and other agricultural resources, would be likely to result in the loss of the equivalent of a year's production in any case, even in the absence of such problems as fuel shortages, transportation breakdowns, and destruction of processing plants.

Thus it may be that the most important implications of the TTAPS study for agriculture may relate to a time frame not explicitly described by their calculations, namely, the second and third year after the war. Climatic disturbances extending into that period, even if much more modest than those of the nuclear winter itself, might well imply the loss of most production for additional growing seasons.

All of the foregoing considerations, however, appear relatively minor compared to the uncertainties associated with massive ecological disruption on a global scale, which Ehrlich et. al. suggest would be induced by the nuclear winter. Here we approach the ultimate limits of scientific inquiry into the consequences of nuclear war. If there is reason to believe that nuclear war would not alter the natural environment in such a way as to make it permanently and fundamentally hostile to man, it is not because we really understand in scientific terms how the natural environment operates. It is because of an essentially common sense appraisal that the global environment is "large" -- much larger than urban civilization, for example --

while nuclear war is comparatively "small". But the prospect of nuclear winter and its attendant biological impact indicates that a war that is very small compared to the strategic arsenals may be very large in its impact on the global environment, quite possibly producing perturbations of a magnitude unprecedented in the history of the human species. If this is true, confidence in the survivability of the species, let alone of the United States of America, is unwarranted and will remain unwarranted.

Finally, it should be emphasized that climate changes less drastic than those estimated by TTAPS might still have significant implications for the prospects for national survival. As suggested above, this would be particularly true if the changes extended more than a year after the war and adversely affected the prospects for agricultural recovery in that time period.

Strategic Implications

In conclusion, I would like to comment briefly on the implications of the nuclear winter hypothesis for nuclear strategy and arms control. If the hypothesis should emerge essentially intact from the intense scientific scrutiny that it will surely receive, the most important question by far is whether the political and military leaderships of the United States and the Soviet Union will acknowledge this reality and accord it appropriate weight as a determinant of their behavior. If they do so, the world will promptly become a great deal safer by virtue of the drastically changed incentives for the initiation of nuclear war by a preemptive strike, in the context of a severe crisis. Of particular importance here is the fact that the society of the attacking nation would be destroyed by the effects of its own weapons, regardless of any retaliation. The world might also become safer, ultimately, through agreements on the reduction of strategic arsenals (as urged by Sagan, 1984). On the other hand, if leadership groups are not persuaded both of the reality of nuclear winter and of its acceptance as reality by the other side, neither the improvement in crisis stability nor the improved prospects for arms control are likely to materialize. Therefore, the highest priority for the near future is to subject the nuclear winter hypothesis to the most careful scrutiny and discussion, in such a manner as to maximize the chance that the ultimate conclusions will be accepted where it counts.

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Senator **Proxmire**. Thank you very much, Mr. Winter.

I understand, Mr. McLoughlin, you haven't had a chance to prepare a statement and I understand that because you come with very little notice. Do you have any statement you would like to make for us?

Mr. **McLoughlin**. Senator, I do not have a prepared statement but I would like to make a few opening comments, if I might?

Senator **Proxmire**. Go right ahead.

STATEMENT OF DAVID McLOUGHLIN, ASSISTANT ASSOCIATE DIRECTOR, STATE AND LOCAL PROGRAMS AND SUPPORT, FEDERAL EMERGENCY MANAGEMENT AGENCY

Mr. **McLoughlin**. As you probably know, FEMA is involved in a wide variety of emergency activities, as you referenced earlier. We are involved in disaster relief and certainly there is a Presidential declaration on the tornado at Barneveld that you referenced earlier that we're administering right now.

We're also involved in earthquake and hurricane preparedness. We're involved in dam safety, in offsight preparedness around nuclear power facilities. We are involved in continuity of government. We're involved in mobilization preparedness and, as you acknowledged already, in the national strategic stockpile activity as well. All of this, with the national flood insurance program, the flood planning management effort.

When FEMA was formed it brought together a wide variety of separate emergency responsibilities at the Federal level. It included in that certainly the civil defense responsibilities.

And the point that I would make about our civil defense responsibilities is that there is a specific congressional legislative mandate that directs FEMA to develop a civil defense program. It stems from the 1950 Federal Civil Defense Act, which has been reaffirmed as lately as 1980 when title V of that act was added and specifically directed us to consider crisis relocation, evacuation and in place protection, along with other elements such as warning, emergency operating centers, training, education and a variety of additional functions.

In 1981, the Civil Defense Act was again amended to include natural disasters in the definition. So that today the definition of civil defense includes not only nuclear attack but includes natural disasters as well. Based on that fact, plus the bringing together of a wide variety of emergency functions into FEMA in 1979, we have evolved to a point that we are—in the last 2 years, we have embarked on a strategy for implementing all of these separate authorities that we have in the emergency management field in what we've called an integrated emergency management system response, a strategy for implementing.

It trades on the notion that there are a common set—there is a common set of functions across all emergencies, be it tornadoes, flood, hurricanes, or nuclear attack. In all cases, you have to look at the warning of people. You have to look at the emergency operating center activity for direction control purposes, emergency communications, emergency medical services, including evacuation and shelter, which clearly are parts of any emergency planning activity.

So the implementation of these wide range of responsibilities that we have are, indeed, implemented in an integrated emergency management system form. Without commenting on that anymore specifically, we may have some additional comments in the question period, I would comment specifically on the purpose of this hearing that relates to nuclear winter and its impact, certainly, on our programs.

We are aware and have been aware and continue to be, of the tax study, and we will be participating in the NOAA study that will be reviewing more in depth the efforts of Mr. Sagan and his group. We do expect to participate at the executive level, and we expect to have one of our meteorologists and physical scientists participating in the working group efforts.

We are aware of the fact that there are uncertainties associated with this, but we certainly are aware too that the likely conclusion over time is that there will be some legitimacy, certainly, to the nuclear winter concept. And maybe one of the principal questions has to do with the threshold at which the effect may occur.

With respect to our mission, specifically, in civil defense, and it's been alluded to in previous testimony, we view our work essentially as one of trying to increase the saving of lives in a nuclear attack environment or certainly in the peacetime emergencies, as well.

I would acknowledge up front that our current preparedness, civil defense preparedness efforts, particularly for nuclear attack, are inadequate. I don't believe they are at the level of effort and the level of resources that are being provided at the moment, that there is any opportunity to develop a system that is able to meet the complex and difficult problems associated with a large-scale nuclear attack.

I'd like and hope that we are able this afternoon on our questioning to separate what our current level of preparedness is from what we believe may be appropriate as specific preparedness measures that could be taken, even though we do not have preparations for them today; that may save an increment of lives in a nuclear attack.

We acknowledge freely that no civil defense program can, indeed, insure the survival of the entire population. We will have millions of deaths, regardless of what kind of a civil defense program that we have.

Our concern is trying to provide an incremental increase in the number of lives saved for a specific kind of attack.

And that concludes my statement.

Senator **Proxmire**. Thank you, Mr. McLoughlin, very much. I want to correct any misimpression I gave. I realize how appalling it must be to many people, many of you listening, who hear a tornado that hits a village compared with a nuclear explosion. Obviously, people living within several miles of a nuclear explosion—part of them would disappear, the others would burn to death, and the casualties would be overwhelming. I realize that. But what I am trying to point out is that most people, including the fine presentation we just got from Mr. Winter, implies that there would be somebody left. He used a 10-percent figure. In Arnaveled, which was a terrific disastrous area, in a conventional war would look about the way some of those Polish villages looked, only 2 percent of the people were killed.

And I just wanted to indicate that however inadequate the most elaborate protection system we could devise might be, in my view, it would be worthwhile, but I realize there are terrific problems involved in doing this, and that's one of the reasons why we're having this hearing.

Mr. McLoughlin, I realize that the Civil Defense Act of 1980 mandated a relocation program of the type proposed by the administration, but since that act was adopted, there have been new scientific findings that nuclear war would cause a nuclear winter, and there have been scientific findings about other effects, such as on fresh water and agriculture.

Was your Agency aware of these studies when you prepared your relocation program, and did you advise the President about them before it was announced?

Mr. McLoughlin. I think it was a fair statement to say that we were aware of all of the available studies that dealt with the civil defense arena with the exception of the nuclear winter issue as it's been more recently defined.

Senator Proxmire. Why weren't you made aware of it? Why was there that failure to understand the defense situation?

Mr. McLoughlin. The nuclear winter? The nuclear winter, sir?

Senator Proxmire. No, the other scientific findings. You indicated that you were somewhat aware of the nuclear winter, as I understood your response.

Mr. McLoughlin. No, we were not aware of the nuclear winter. I think we were aware mostly of the other studies that I believe you had reference to.

Senator Proxmire. Why weren't you aware of nuclear winter?

Mr. McLoughlin. Well, the——

Senator Proxmire. It got a lot of attention.

Mr. McLoughlin. Well, we certainly have been, as long as it has been—you know, the consciousness and awareness of it in the literature, and we've been aware of studies that have been done in this arena, certainly, the ozone studies that were done by the Congressional Office of Technology Assessment and the National Academy of Sciences. And we're aware of those types of studies, specifically, you asked me, as I understood it, that in 1980, when the crisis relocation portion of that amendment was added, whether or not we were aware of nuclear winter. And to my knowledge——

Senator Proxmire. I realize that the Civil Defense Act of 1980 mandated a relocation program of the type proposed by the administration, but since that act was adopted there have been new scientific findings. And of course, the most spectacular and serious is the nuclear winter.

Mr. McLoughlin. Yes.

Senator Proxmire. The President's program was announced this year, and the nuclear winter thesis was discussed in detail last year.

Mr. McLoughlin. Senator, the administration, in 1981—I'm sorry, 1982, the first full administration budget—proposed a $252 million civil defense program. At that time, it was part of a $4.2-billion, 7-year program. That program was rejected, in effect, by the Congress. The $252 million program was—that first year we received $147 million. Subsequent to that, we have asked the Congress, in the last 2 years, for $252 million in 1983 and again in 1984. We received in 1984—our current budget is $169 million. The administration's program was, in effect, designed prior to the nuclear winter concept. Now that we are aware of nuclear winter, as the other agencies are, indeed, we expect to participate in those programs that will define the specific characteristics of that more precisely.

Senator Proxmire. So you expect the program will be changed for next year?

Mr. McLoughlin. It's a function of what comes out of some of the nuclear winter studies. We see nothing on the horizon at the moment to change our current program, except for the nuclear winter effort. If the nuclear winter effort is certainly reaffirmed, and wherever the threshold might very well be, for those program elements—our current program, we believe, is applicable below the threshold. Above the threshold, it's likely that it will impact the current nature and design of a civil defense program. What that design will be, must await, really, a more definitive explanation of what the nuclear winter concept is.

Senator Proxmire. Well, has FEMA ever formally reviewed nuclear winter and other studies and prepared a report on the basis of that review, recommending changes in the civil defense program?

Mr. McLoughlin. We have been, over the last year, now only in-house, but we have a number of contract efforts, as well, and people that have been working on civil defense efforts for some period of time and are quite knowledgeable in the area, and we've had them reviewing a number of aspects of the nuclear winter concept. We are expecting to continue to participate in the studies that define more precisely the impacts of a nuclear winter, but in terms of changing the current design of the program, Senator, our best estimate right now is that that is not appropriate for us to change policy until we know more precisely what the nature of the environment would be that we're planning for.

Senator Proxmire. It will be a year or so before we get the results of that study.

Mr. McLoughlin. That's correct.

Senator Proxmire. Meanwhile, we have the Defense Department this morning that acknowledged that they expect that there will be a confirmation—there doesn't seem to be much dispute that it will have a very serious effect on the climate, on the environment, and the situation, therefore, is far different with a nuclear war, and therefore, it would seem to be that the changes should be underway long before we get the final report.

Mr. McLoughlin. Senator, I think that we will be trying to move as well as we can, as well as we understand the environment, we will try to move with some options that are, in effect, available to us. And if there are any options—you know, Senator, as Mr. Sagan testified yesterday, you know, he's talking at one end of the spectrum about mankind not being around at that point in time.

Whether or not there are legitimate efforts that can be made to assist with that very difficult problem, we simply are not aware of them yet. Until we can understand more precisely what it is that we're faced with, it's inappropriate, we think, to make major shifts in our program effort.

Mr. Wagner, this morning in his testimony, pointed out that it took us roughly 5 years from the time that we first understood the fallout problem, until we understood it well enough to try to design ways to deal with that. Our guess is that same sort of thing is likely to happen in the nuclear winter arena.

Senator **Proxmire**. Well, I hope it doesn't take 5 years. I would also hope, however, that there be an intense effort to study this and to look for options and ways in which you can do whatever can be done, of course, to meet this absolute disaster.

Mr. **McLoughlin**. Senator, we will be trying to move as rapidly as we can into this arena, consistent with a data base. I would point out that even with the ozone, with the first knowledge of the potential depletion of an ozone layer in 1975 by the National Academy of Sciences, it was not until 1979 that the Congressional Office of Technology Assessment, their findings, their report identified the fact that they thought the conclusions were not near as serious as originally indicated. And so the 5-year period, from our perspective, is not unreasonable to try to understand a problem as difficult with the degree of uncertainties that are associated with the models and the basic input.

Senator **Proxmire**. I know you're very sincere in this, but it seems to me that it appears that relocation, for example, would not be an effective option in the event of nuclear winter. It would certainly be enormously modified. You should be looking for other answers under those circumstances.

Mr. **McLoughlin**. Senator, I understand your guidance. I would make the point that since man has been on Earth, there essentially have only been two ways, generically, to protect people. Only two. I'm sorry, but there just are no more. One is either to shelter people in place or the other is to evacuate them.

Senator **Proxmire**. One is what?

Mr. **McLoughlin**. One is to shelter people in place and the other is to evacuate them. This is given the event occurs. This same thing is true for hurricanes; it is true for tornadoes; it is true for preparedness around nuclear powerplants; and certainly, it is true as well for nuclear attack.

There may be some options that we are simply unaware of.

Senator **Proxmire**. It seems so transparently clear to me, that if you have this phenomenon of nuclear winter, that you have an entirely different situation than you would have for relocation, moving people out of a shelter-in-place mode, to a situation where they would move into the countryside. They would move into a countryside which was pitch dark for weeks, which was 13 below zero with no heat anywhere available. They'd freeze to death; they'd starve.

That just seems to make relocation the wrong kind of solution, whereas, under the other assumptions that the climate would be benign, wouldn't be affected, relocation might have made some sense.

AVAILABLE

Mr. **McLoughlin**. Senator, my inclination is to agree with you. You know, in terms of trying to understand the magnitude of that problem, it does seem that relocation may very well not be a viable option. As I've acknowledged, I think up to a threshold point at which nuclear winter would occur, the current design of the Civil Defense Program, based largely on evacuation, crisis location, makes some sense, in our judgment, in terms of trying to increase the number of survivals.

After that point, my guess is that there are likely to be significant impacts on the program and relocation may just not make any sense at that point. I'm reluctant to make that statement, because simply we haven't dealt with it long enough.

Senator **Proxmire**. Mr. Winter, would you explain what you mean, comment, if you'd like, on Mr. McLoughlin's statement and explain what you mean when you say that the nuclear winter findings raise further doubts about the effectiveness of extensive programs to protect U.S. population and industry from large scale nuclear war.

Mr. **Winter**. Yes, I'd be glad to.

My reference there is to extensive programs, and by extensive programs, I mean programs costing in the aggregate tens to $100 billion, and realized, presumably, by expenditures at the rate of a few billion to, say, $20 billion per year.

I think there is a serious discussable question about whether programs of that magnitude would lead to national survival in the case of a nuclear war, in the absence of nuclear winter. If the nuclear winter prospect is real, then that probably forecloses the possibility that programs of that magnitude would prove to be effective.

I don't think there is any substantial question at all, but what the current program, the current level of effort is very, very inadequate, very likely to be ineffective in the contingency of large scale nuclear war. And that would be my view regardless of whether nuclear winter occurs or not.

Senator **Proxmire**. Take the worst case of a nuclear winter. Are you saying, Mr. Winter, that we should not be prepared to do anything and, in effect, write off the survivors?

Suppose only a few percent of the population survive. That could still be several million people survive, and a million people would be a tiny percentage of the population, but should we say now, "Let them die," or "There is nothing that can be done to prevent them from dying?"

Mr. **Winter**. My main reaction to that would be that I cannot imagine a plainer or more compelling objective for U.S. national security policy than to avoid that circumstance.

Senator **Proxmire**. Well, there is no question about that, and you keep talking about national survival, which I think is something that is very pertinent and appropriate. You also give us a scenario for a situation where there wouldn't be an organized society. It would be broken down into, at best, regional groups, and as you say, marauding gangs, but still, human beings with a desperate possibility that they may disappear.

Mr. **Winter**. I think there is, perhaps, some point to trying to make provision for that contingency. That, in effect, would be an effort to create a basis for these small fragments of the society to reconstitute themselves. That would be a very different undertaking than the undertaking of trying to defend the Nation itself as a modern state.

Senator **Proxmire**. Well, do you think that the civil defense agency should prepare for that?

Mr. **Winter**. No, I think there's so many other objectives, both in the civil defense areas and elsewhere, that are calling out for resources, that that would not be a——

Senator **Proxmire**. Then your answer, as I understand it, and I don't want to be unfair—your answer is, there's nothing we can do?

Mr. **Winter**. If the nuclear winter contingency is real, then I don't believe that there is an important role for civil defense in trying to——

Senator **Proxmire**. Well, all right. Forget civil defense. Is there anything we can do, anybody? Is there any kind of action that could be taken now—any?

Mr. **Winter**. Your question relates to the contingency that there is a nuclear winter?

Senator **Proxmire**. The question relates to the situation which you properly paint as about as disastrous as you can imagine, except that some human beings are left, a few million, 1 percent, maybe, 2 percent of the population, but still a remnant of human beings left. What do we do? Do we let them perish?

Mr. **Winter**. Well, if the situation arose, I am sure that some of those people would try to cope with the situation and that there would be some role for people trying to help each other to cope with that situation. But if we're talking about preparation for that situation, I don't have any clear idea of what it is that you do to significantly enhance survival under the sorts of conditions that the TTAPS study describes.

Senator **Proxmire**. I've leaned on you so much, Mr. Sagan, that I hesitate, but you've done so much work in this area, and you've thought about it more than anybody else—do you feel that there is nothing we can do under these circumstances? And you certainly expressed brilliantly yesterday your feeling about how important it is that we try to keep the human race still alive.

TESTIMONY OF CARL SAGAN, PROFESSOR OF ASTRONOMY AND SPACE SCIENCES, CORNELL UNIVERSITY

Mr. **Sagan**. Thank you, Senator Proxmire.

I would respond as follows: The World Health Organization's rough estimates of survivability after a 5,000 to 10,000 megaton nuclear war that you referred to were that some 1.1 billion people would be killed outright, and another 1.1 billion people would be killed unless given prompt medical attention—which is unlikely, of course, because the doctors and the hospitals would be destroyed as well. So the immediate effect of nuclear war, then, according to WHO, might be some 2.2 billion people killed. As you pointed out, that means that more than half the human population of the planet survives.

Now the question is, if nuclear winter effects are as serious as our calculations indicate, the survivability of that remnant in northern latitudes, especially in the United States and the Soviet Union, the prospect for their survival is much less than at more remote regions on the planet. If we were concerned about survival of the human species, then I think we would be spending large amounts for civil defense in Patagonia and Tasmania. That would be the right thing to do, if we genuinely were concerned about the welfare of the human species.

If we're concerned only about the well-being of Americans, that's a much tougher prospect. What we have to imagine are shelters which would be suitable in terms of food, heating, water supplies, radiological defense, defense against pyrotoxins, the toxic gases from the burning of cities, and so on, that would work at least for months, but possibly for many years. And then there are awkward questions—which Americans are permitted to go into such shelters? How are they decided, and do they involve the leadership? How about the families of the leadership?

And even if all those questions were resolved, what about the rest of the world? How does the rest of the world look at the United States, if the United States, one of the two nations able most likely to trigger nuclear winter, sets about making provision to protect a remnant of its population and lets the rest of the world look out for itself.

So I think I would echo the implications of Professor Winter's remarks, as follows: If the Senate, let us say, were seriously contemplating spending tens or hundreds of billions of dollars on civil defense, is that the best way to spend that large amount of money to save the population? Wouldn't it be better to spend that money in, for example, better verification of strategic treaties and better thinking out of ways to make massive reductions in nuclear arms, or a wide range of other possibilities?

If I can make just one other remark. May I?

Senator **Proxmire**. Of course; yes.

Mr. **Sagan**. Thank you.

On the question of Mr. McLoughlin's remarks about FEMA, it is, of course, reasonable to be cautious about a new finding and want to work it into an agency like FEMA's purview. But what strikes me here is how there are two different standards of evidence in two different times. Before the nuclear winter findings were published, FEMA consistently stated that there was nothing to worry about as far as climatic effects were concerned. There were repeated FEMA statements that the climatic effects were negligible and, in fact, some statements by FEMA officials that all you'd have to worry about the climate were pretty sunsets all over the world. You know of such statements.

Now that was not based on any detailed studies. That was based upon casual remarks, reading one paragraph in a 1975 National Academy of Sciences study, that sort of thing.

But now, when there is a serious possibility of nuclear winter, we hear from FEMA exhortations to take great caution. What strikes me is how different the FEMA standards of evidence were before compared with after the nuclear winter studies were announced.

Thank you again, Senator.

Senator **Proxmire**. Well, thank you very, very much, Mr. Sagan. Now Mr. McLoughlin, would you respond?

Mr. **McLoughlin**. Surely. I would simply differ with Mr. Sagan. It is clear that we're being cautious with respect to what nuclear winter is right now. I think it is not an accurate statement at all to say that we had only made cursory reviews or other research activities. FEMA and its predecessor agencies have been involved in research in the nuclear attack environment in trying to understand it and what ought to be done in the way of shelters and to being able to identify shelters in existing facilities around the country since the mid-1950's, when FEMA was first—and its predecessor agencies—defined in 1950.

Senator **Proxmire**. How many people do you have involved in doing that right now?

Mr. **McLoughlin**. Right now we have about 2,500 people in the agency, and we have about 660 people budgeted in civil defense. In civil defense, by itself——

Senator **Proxmire**. How many involved in studying what you can do and should do in the event of a nuclear war, which of those people?

Mr. **McLoughlin**. A great deal, Senator, of our study work is not done in-house. It is done by contractual activity. We don't have——

Senator **Proxmire**. Can you tell us what contracts you've given for——

Mr. **McLoughlin**. A nuclear winter?

Senator **Proxmire**. Yes, sir.

Mr. **McLoughlin**. We have given none. We are participating in the study, the NOAA study. We are certainly—we don't view ourselves at the center focus of trying to try and study the nuclear winter project.

Senator **Proxmire**. Well, then what Mr. Sagan said is correct. You—as I understood it, you're not doing anything with respect to reacting to this nuclear winter revelation?

Mr. **McLoughlin**. There were two things that he made a comment on. One, was support the caution on nuclear winter. And I have indicated that our efforts today are only dealing with participation in the NOAA study on—we have a research budget this year, Senator, that is less than $5 million, and how much of that research effort that we use in this—we need the leverage and need to understand this with agencies that have a more relevant expertise to understanding this problem, mostly, the climatic and meteorological people in the Federal Government.

What my first comments were addressed to was an apparent comment that dealt with our—what I interpreted to be—and I hope I didn't misinterpret the comment that there was a casualness, maybe, is the appropriate word, to do research on the attack environment, absent nuclear winter. That I think is not an accurate statement, and I am not prepared to agree with that at all.

I think for three decades we have been doing work and have sponsored work in this arena to understand—let me—Senator, may I give you a few examples?

Senator **Proxmire**. There seems to be a very leisurely aspect to the way you're dealing with nuclear winter at the present time.

Mr. **McLoughlin.** We certainly don't view internally that it's a leisurely aspect, but we don't see ourself, Senator, as the central agency for trying to understand the nuclear winter concept.

Senator **Proxmire.** Isn't that shocking, when you think about it, Mr. McLoughlin, you're not a central agency? I can't think of a more useful action that the Government can take, except, of course, prevent nuclear war, which all of us realize is the No. 1 priority, by far, and the war's something else, but after that, I mean, what we can do to protect people who would survive.

Mr. **McLoughlin.** Senator, when I indicate that we not at the center of trying to understand the problem, I don't mean that we don't have a sincere, and continuing, and necessary interest in that, because, clearly, we do, which is the implication in your statement.

What I'm suggesting is that we do not have the expertise as an agency to try to deal with the uncertainties that are associated with nuclear winter. We have one meteorologist——

Senator **Proxmire.** You should ask for it. You should ask for the resources, so you can acquire the expertise.

Mr. **McLoughlin.** I believe we have been asked for that, which would have permitted us to do more in this area, with a $252 million program that we have asked for for the last 3 years, and have been unsuccessful, really, in obtaining. A significant portion of that——

Senator **Proxmire.** Well, I'm not sure that the Congress is wrong in not providing that, because what we need is a program that will do something, do the job, but provide some significant, credible protection of some kind.

Mr. **McLoughlin.** Senator, we believe that below the nuclear winter threshold, that the program that we have proposed, which I've clearly acknowledged is inadequate, clearly believe that that is a reasonable program to try to provide for the savings of lives below the nuclear winter threshold.

I stand on that statement.

Senator **Proxmire.** Can you describe the relocation program, briefly, and explain the underlying assumptions with respect to the magnitude of nuclear war——

Mr. **McLoughlin.** Yes, sir.

Senator **Proxmire** [continuing]. With the nuclear war scenarios, number of weapons, megatonnage, numbers of people that would be relocated, how many lives would be saved?

Mr. **McLoughlin.** There's a lot of questions there. Let me try to do it just briefly.

Senator **Proxmire.** Why don't we just take them one by one?

First, the magnitude of nuclear war. What would you assume on that?

Mr. **McLoughlin.** Well, in our planning, Senator, we have looked at counterforce attacks that might be anywhere from 2 to 20 million casualties. To the other end, which is attack against the United States at the level of about 400 separate risk areas with 145 million people in those risk areas, and the probably consequences in the worst case scenario there, at the order of 5 to 6 megatons, 5,000 to 6,000 megatons, is in the neighborhood of 170 million, maybe.

So there is a range of——

Senator Proxmire. 170 million people?

Mr. McLoughlin. Casualties.

Now you've asked then, the question, what is the crisis relocation program? There are two options available to us. One option, in effect, and we are mandated to deal with this option, you know, as I have said earlier, to deal with the problem.

One option is to provide shelters in place. Blast shelters, essentially, in the risk areas. That's a tens of billions of dollars program cost, even if you are able to spread that over time, with the constant escalation.

We have felt for some period of time that that is not—we would not be able to sell that kind of a program.

The alternative that's left then is to relocate people, and our relocation concept is built on this set of assumptions; 145 million people in the risk area, at risk from direct effects. And additional—the rest of the population at risk from fallout, potentially.

Senator Proxmire. That was before your nuclear winter came along. Now they're at risk from freezing to death, and starving, and living in darkness.

Mr. McLoughlin. Well, Senator, if I might, let me try to build a little bit of a case for this, and then respond to specific questions.

Our crisis relocation planning is built on the assumption that we would never evacuate our cities first. Generally, we would do this only in response to a Russian evacuation. Our best estimates from the intelligence community, not our own, certainly, but from the intelligence community, is that it would take Russia, because of the differences in road systems and differences in numbers of vehicles, essentially, 1 week, to evacuate and provide adequate fallout protection.

Senator Proxmire. How long?

Mr. McLoughlin. Seven days. Roughly, 1 week. The intelligence community also says that they would probably know within the first day whether or not the evacuation was beginning to occur. Set in a climate of increasing international tension, our planning base, then, for a crisis relocation planning effort is based on roughly, 3 days.

We believe that with the—and we've been at this since about 1973, trying to understand the problem as well as we can—we have had the transportation communities, the food communities, the medical communities, assist us in trying to deal with the problems. We believe we can evacuate that—not we, not FEMA coming in to do it, but State and local governments—cities can be evacuated, about 60 percent of the people of the 145 million, in 1 day.

Senator Proxmire. One day.

Mr. McLoughlin. One day.

Senator Proxmire. Twenty-four hours.

Mr. McLoughlin. Twenty-four hours; yes, sir. We believe 80 million——

Senator Proxmire. Have you submitted that to any independent judgment?

Mr. McLoughlin. We've had any number of people to look at this—and the only thing I can say, Senator, and certainly, we'll provide you——

Senator **Proxmire**. Have any of them agreed that you're right?

Mr. **McLoughlin**. I'm sorry?

Senator **Proxmire**. You say you've submitted this to any number of people. Do they say you're right or wrong?

Mr. **McLoughlin**. Well, part of the problem also is, in terms of our critics, and they are legion, and we accept that—part of the problem is trying to get people to consider and think about the problem long enough to really understand and find out whether or not you could do 60 percent in 1 day.

Cities like Dallas and Atlanta that have reasonable distribution systems are easier and can be done easier than a city like Milwaukee, in your case, where half of it butts up next to a river, and you lessen then the exit corridors. People frequently want to use New York City as an example. Let me give you the other figures; 60 percent in 1 day, 80 percent in 2 days, and we think 95 percent in 3 days. We believe that those are not unrealistic estimates, based on loading that transportation people normally do.

Here in this metropolitan area there are 3 million people, Senator——

Senator **Proxmire**. Can I interrupt just to ask, can you tell us the outside experts in transportation, whatever, who've given their judgment that this is feasible?

Mr. **McLoughlin**. Senator, I'm not prepared at the moment to give you a list of names, but certainly we can provide those for the record. We have had a number of people that are knowledgeable in the transportation industry, and I'll be glad to provide you with summaries of the reports and provide you with the names of the people that did the work for us, the names of the company.

Senator **Proxmire**. You say in 1 day you could evacuate most of our cities. New York City would take 3 days?

Mr. **McLoughlin**. New York City is likely to take longer than 3 days. New York City is a terribly complex problem. We would expect that 20 percent of the people would probably never evacuate, even if asked to. The surveys that we've done, the 1982 survey that we did, indicated that—and Gallup did it for us, we didn't do it ourselves—indicated that two-thirds of the people said that they would evacuate on direction from responsible officials; 50 percent of them said that they would go even if—as a response to their perceived threat—even if no advisory was ever given. And we have evidence to support that.

Around Three Mile Island there were 345,000 people within the first 15 miles; 145,000 of those 345,000 people evacuated, and there never was an order for evacuation given.

Senator **Proxmire**. I would think it would take a lot longer, if they went without being directed, and ordered, and organized. With half the people in New York City trying to get out of it, it would seem to me it might take a lot longer.

Mr. **McLoughlin**. Senator, let me try to give you some other examples of real-life experience that we have.

We can't evacuate New York City to know whether or not we can do it in 3 days. We can't evacuate Dallas to know whether or not we can do it. But let me give you one real-life example.

In December 1982—we are involved, as I told you, for the offsite emergency preparedness activity, the offsite—we're esssentially a consultant and adviser to the NRC for offsite preparedness around nuclear facilities. The Waterford 3 plant in Taft, LA, was part of the planning process, and they were to a certain point where they had developed an evacuation plan. Up the road a ways is a chemical company that had a serious incident in December 1982. The incident was serious enough that it required an evacuation. The critics, and there's a whole process of intervenors for the Atomic Safety and Licensing Board hearings, so there are a lot of critics of the evacuation planning around nuclear-power facilities.

The estimates were 7 hours. The critics said it couldn't be done in 7 hours and certainly said we may not be able to do it at all. In December when the incident occurred, it occurred at 5:30 in the morning, in a driving rainstorm, dark, people in bed, 17,000 people were evacuated, using that evacuation planning effort and the associated transportation planning in 2½ hours without incident, when the critics indicated that we couldn't do it in 7 hours, not we, but the local people couldn't.

So we do have evidence. Senator, half a million people have been evacuated, orderly, and in reasonable time in face of hurricanes. In the Second World War, in London, right before the war started, evacuation was ordered of London. One and one-half million people evacuated during that particular period of time.

Senator **Proxmire**. How long a period?

Mr. **McLoughlin**. Senator, I simply do not have it, and I should—2 to 3 days. I'm helped.

So it occurred in 2 to 3 days, 1½ million.

Senator **Proxmire**. The population of London was what? Seven million?

Mr. **McLoughlin**. Well, it was about——

Senator **Proxmire**. One million evacuated?

Mr. **McLoughlin**. No; I think it was more in the neighborhood of between 3 and 4 million people, because subsequent to the war, it was determined that 2 million people had evacuated prior to the order to evacuate.

The key to the point that I'm trying to make is that people are going to evacuate our cities, Senator, if, indeed, they perceive threat. They do it in hurricanes; they do it in floods; they do it in the face of perceived threat, if they believe there's an opportunity to move to safer areas. They will do it from the New York cities, we believe.

Therefore, we believe that partly what we have to do in an evacuation is to deal with that, is to get ahead of that power curve and try to deal with those people that are out there, regardless of whether or not we wanted them out there. Even if we said stay put, we think they're going to go.

And so, if Government has a responsibility, which you clearly said earlier you thought they should have, even if we didn't order one, we believe it'll occur, and we ought to be there trying to deal with the necessary sustaining of whatever lives we can.

And I know I've made a lot of comments at this point, but Senator, let me give you one other specific from our perspective.

The food problem is a little bit different. Let me take the water problem for a moment. One of the things that we know about fallout is that most of it is not soluble. Therefore, there's a lot—the concluding statement—without going into too much detail, the concluding statement to that is that from our perspective, no one should ever be denied water on the grounds that it is potentially contaminated. The worst thing that happens, in terms of a—basically—people accepting heavily contaminated food and water, from the studies that have been done, suggest that what we're talking about, in terms of the ingestion, is maybe, at the most, a doubling of the cancer rate 30 years down the road.

We're talking about a cancer rate in this country right now of about 400,000 to 500,000 cases per year. And we're talking about a doubling of that from the potential of eating contaminated food. And we're talking in the neighborhood then of roughly, you know, an equal number. When you consider that number, relative to the number that could conceivably die from the lack of food or the lack of water, that seems to be not—how do you deal with ever saying that 500,000 is an acceptable burden. You can't say that, but without saying to people: Look, you should never deny yourself the opportunity to water, based on the fact that it may be contaminated, because—and therefore, have people die—is simply an unreasonable bit of guidance to provide people from our perspective.

Now I could comment on the medical area, and I could comment on the food area.

Senator **Proxmire**. Let me ask Mr. Winter to respond to this.

Mr. **McLoughlin**. Certainly.

Senator **Proxmire**. Mr. Winter, go ahead.

Mr. **Winter**. Yes; I appreciate the opportunity. It seems to me that the crisis evacuation program is perhaps an extreme example of the sort of approach to civil defense that I personally think is inappropriate. The program is focused entirely on the problem of confrontation with the Soviet Union, as we have just heard, and so presumably, this evaluation program is supposed to make some kind of a significant difference, either to the actual consequences of a nuclear war or to the political bargaining between the United States and the Soviet Union, in the context of crisis.

Now under either heading, if it's reasonable to spend $1 per person per year to prepare for the consequences of nuclear war or to prepare to strengthen the President's hand in a bargaining situation, if that's reasonable, then, it's reasonable to spend a vastly larger amount than that and to go ahead and do something that would have some prospect of effecting the survival of the Nation, if the nuclear war actually occurred.

The evacuation program doesn't do anything at all about the problem of reconstructing the society or reconstructing the food supply system, in the event that the nuclear war should actually occur.

One would think that because it does not do anything about those problems, that it's also not worth very much from a bargaining point of view. One would hope, actually, I think, that the President would not make very different decisions in a situation when we had the evacuation program than in one where we did not.

Senator **Proxmire**. Mr. Winter, don't you or do you feel that the nuclear winter concept dramatically changes the feasibility of evacuation?

If I'm living in Milwaukee or Madison or wherever, and I'm told I should evacuate to a county 20 to 30 miles out with a prospect that the nuclear war may begin at any time, I'm going into an icy cold desert. It's like wandering around near the North Pole.

Mr. WINTER. The prospect of the nuclear winter certainly underscores the difficulties that the evacuated population might face, but it would face enormous difficulties even in the absence of nuclear winter, and there is nothing in the existing Civil Defense Program to deal with those difficulties.

So I do not believe that program represents something that should be taken seriously, really, as a response to the hazard of nuclear war to the population or to the strategic issues to which it is sometimes related.

Senator PROXMIRE. Do you dispute the arguments Mr. McLoughlin made or the statement he made that we could relocate within 3 days—24 hours, for most of our population and 3 days for even the congested cities like New York?

Mr. WINTER. I really do not have the technical basis for judging the plausibility of those remarks. It seems somewhat implausible to me, but on the other hand, just to give an illustration, I think that if those calculations are to be the basis of national policy, and our approach to survival in the nuclear age, then I think we ought to do a lot more to find out whether there is any sense in those calculations, even extending to the kinds of evacuation exercises that have just been described as being impossible or inappropriate.

Senator PROXMIRE. Mr. McLoughlin, Secretary of Defense Harold Brown said that relocation makes no sense for the Soviet Union, since we will simply retarget our warheads.

Can't the Russians simply retarget, as well?

Mr. MCLOUGHLIN. Senator, I guess the direct answer to your question is, yes, they certainly aim the nuclear weapons, and they can target them any way they want to. Our expectation is, and the Department of Defense planners that we have worked with have indicated, and I believe it was acknowledged this morning, although it was acknowledged that it may be playing on words too heavily that people per se are not the target. It is the industrial—either the counterforce areas or the countervalue targets, our industrial capability. That's what target is likely to be a potential target. And other selected—I don't want to just put industry as the only target. People happen to be colocated with industry, though. Therefore, people—you know, it is—people are going to be in our large cities, and in our work with the Department of Defense, any city over about 50,000 turns out to be a target area. It's among that 400,000 that I referenced earlier.

From our perspective, it simply seems not reasonable, because of the density of the population, to retarget and use remaining weapons to retarget against a relocated population, but I would hasten to add, Senator, that's not again our expertise and our agency. We are not targeting people; we are not experts in the Russian targeting efforts, and from that standpoint, we must rely on other agencies that have better expertise in that area.

Senator PROXMIRE. But we're not targeting. That wasn't my question. The question was, couldn't the Russians do that?

Mr. MCLOUGHLIN. Couldn't they retarget?

Senator PROXMIRE. Yes, sir.

Mr. McLOUGHLIN. I acknowledged they could, but the question is, whether there is a motivation for them to do it.

Senator PROXMIRE. Mr. McLoughlin, did any of the planning for the relocation program include consideration of the possibility that the climate and the environment might be severely affected by multiple nuclear explosions, nuclear winter, in other words?

Mr. McLOUGHLIN. Did any of it to date?

Senator PROXMIRE. You gave us an elaborate listing of the time, it was very helpful, of the time that you felt it would take to move out of the cities and so forth. You specified differences in Dallas and New York, and so on.

Was there any consideration given in the relocation program—has any been given at any time—of the effects of nuclear winter?

Mr. McLOUGHLIN. No, sir, I don't—they have not.

Senator PROXMIRE. Wouldn't that be appropriate?

Mr. McLOUGHLIN. It's appropriate, Senator, as soon as we understand what the—we have a $169 million program, Senator, and that program needs to be directed at a set of resources that's for the full range of emergencies, to include nuclear attack, and also to include the hurricanes and the earthquakes and the tornadoes and the other emergency activities.

We spend—our program this year is about $12 million for our direction control facilities. It's about $13 million for the survey of shelters and the population protection planning effort at State and local levels.

To divert and redesign a program at the national level, that clearly, when this other set of functions are necessary and needed for a portion of the range of emergency activities, including nuclear attack—certainly, even Mr. Sagan has acknowledged the fact that a Civil Defense Program for one nuclear weapon is appropriate. That was in the testimony yesterday.

The question we're talking about, then, is for how many nuclear weapons is the current program appropriate and for how many natural disasters?

From our perspective, the current program is reasonable and one that should be pursued up through that threshold point.

I have acknowledged that our program is not based on nuclear winter; I have acknowledged that we do expect to keep up with the nuclear winter incident and find out whether or not our program ought to be changed, but to change our program today with the degree of uncertainties that are associated with nuclear winter, seems to us to be inappropriate with the level of resources that we have.

Senator PROXMIRE. Well, I hope you'll reconsider that, particularly in the light of the Defense Department's testimony this morning.

Mr. McLOUGHLIN. I was here when——

Senator PROXMIRE. Well, you heard the——

Mr. McLOUGHLIN. Yes.

Senator PROXMIRE [continuing]. Statement that they accept the very strong likelihood, virtual certainty that there will be serious climatic changes, as a the result of a nuclear exchange?

Mr. McLoughlin. Senator, if it was not clear from my opening remarks that that's what I was intending to accept also, I would say that right now. Certainly, we believe that there——

Senator Proxmire. Well, then if you know that, if you agree to that, if you concede it, doesn't it follow that that should have an effect on your relocation program?

Mr. McLoughlin. Yes, sir; I think it does follow. Well, on relocation?

Senator Proxmire. Yes, sir.

Mr. McLoughlin. You seem to be wanting me to make the statement, Senator, that it definitely does have. My inclination, as I said earlier, is to say that, that I think it would have an impact on relocation, as a rational way to deal with the Nuclear Winter Program, that relocation would not do it.

The problem that we have is, how do you put a program together that has to be understood by the general public and accepted by the general public——

Senator Proxmire. Well, let's say, for example, with the nuclear winter thesis, as more and more people read about it, I think you're going to get a much smaller proportion of the population that voluntarily relocates. I think if they can move into Long Island and Westchester and maybe Connecticut and New Jersey, but it's something quite different, if they know they're going to be moving into the Arctic Circle when they do that.

Mr. McLoughlin. Yes, sir; and it's something much different also when a nuclear attack occurs, whether or not that level of attack which is not likely to be known ahead of time, is one below the threshold or above the threshold, and the reason I'm reluctant to make a comment is, let's suppose for the moment that the effort and the program that's designed for a nuclear winter is entirely different than a program that is below the threshold and for natural disasters.

If I accept the fact that that is, indeed true, the question then becomes one of, how do we deal with this in a programmed way and in a responsible way in trying to let the general public know what actions they ought to be taking? It may well be that we have to make some kind of an estimate on the level of attack, before you say, do option A or do option B. But certainly, below the threshold, which may be option A, is a legitimate and responsible preparedness effort for a nuclear attack even.

Senator Proxmire. Now I'd like to ask both of you gentlemen to comment briefly, if you could, Mr. McLoughlin and then Mr. Winter to respond to Mr. McLoughlin.

Has FEMA, Mr. McLoughlin, studied the problem of economic recovery and reconstruction after a nuclear war, and are you working on a recovery program, or would you leave that to market forces?

Mr. McLoughlin. We have participated and have sponsored studies, actually, in this arena, to try to understand the postattack nuclear recovery. The latest one was done in 1973, Senator, POANST-2 [post attack nuclear study]. It included not only FEMA, but a number of other agencies, to try to look at what the postattack recovery programs are in the postattack environment. It included economic issues in that.

We have not specifically dealt with economic issues recently. We have not updated that study, principally, because the resources are not there to update that study. So the direct answer to your question is, we have—by our own acknowledgment, the studies are inadequate for today's environment.

Senator **Proxmire**. Then you would leave it to market forces, the reconstruction and recovery to market forces?

Mr. **McLoughlin**. I guess the direct answer to that is yes.

Senator **Proxmire**. Now Mr. Winter, would you comment on that.

Mr. **Winter**. Yes, I'd like to. In fact, what I would like to do is to just read another portion of my prepared statement, as the first part of my answer to your question.

Although the problem of timely restoration of agricultural production is a key issue in the analysis of the consequences of nuclear war, it has not been adequately studied. So far as I'm aware, there does not exist any study that provides an affirmative basis for the belief that this problem would be manageable under any plausible large-scale attack contingency in the near future. Such a study would be one that dealt, at a minimum, with two key features of the problem posed. One, the existence of deadlines arising from the fact that the population must be fed while the effort to restore production is made, and two, the fact that damage to the transportation system means that the initial postattack economy is a fragmented economy, in which statistics on national aggregates of resource survival are meaningless.

Now to go beyond that a bit, there have been a great many studies of various sorts over the years, but this is a complicated problem, and the effort has not been large in relation to the complications of the problem. It seems to me that it is possible to do a serious study of these questions, and that it definitely should be done, and until somebody can establish an affirmative case for the possibility of restoring agricultural production under at least some of the large-scale attack contingencies, it seems to me that case for the likely effectiveness of civil defense programs, either the evacuation program or more ambitious programs, remains decidely unproved.

Senator **Proxmire**. That seems pretty convincing to me. If you can't have a food supply, you can't live. You have millions of people who might evacuate from cities. The transportation and the production of food would be enormously reduced. Transportation might—might not be possible at all.

Mr. **McLoughlin**. Let me share with you some of the things that we think we understand about the food problem. We think that in the processed food area right now, that the normal supply in the United States is about 100 days. It'll vary from about 80 days in some parts of the country up to 300, 320 days in other parts of the country, based on 2,000 daily diet.

That is an existing resource that we have. In addition to that, Senator, there are a large number of food stocks that are available, grain, supplies, et cetera, generally speaking, of a year, that are available, in addition to that processed food.

We know that there agricultural land is not to be denied—let me take one other instance that you're probably more familiar with than I am.

We have 1 billion pounds of milk products stored in this country—or better—cheese, butter, and food, you know, on top of that.

We have additional supplies that are available.

We know, with respect to growing food, that most of the fallout contaminant is not soluble, which means the great bulk of it is not taken up into the plant itself. Most of it stays within the top couple of branches, certainly, within the top 6 inches of the soil. Crops can be grown. Crops grown on contaminated land will take up some contaminant. If your run that contaminant through a food chain of livestock, it decreases it even further. Maybe by a factor of 10.

Some highly contaminated land could be diverted for other use, like for cotton, nonedible crops, but useful crops.

When you combined these sorts of things, it may make a lot of sense, even though it is not available today, to have a food bank. It is not part of the planning.

I've acknowledged at the outset, that the current programs are inadequate to deal even with less than a nuclear winter concept, but we do know a lot about food.

Senator **Proxmire**. You have, as you say, an enormous, colossal storage of dairy products—I think more than 1 billion pounds, probably 2 or 3 billion pounds, but what good does it do, when you've got to transport that, you've got to distribute it?

There's no way that you're going to be able to make that available to hungry people, is there?

Mr. **McLoughlin**. Senator, our belief is that if fuel is drastically curtailed, and given the maldistribution of those food stocks, it is probably that some people would not be able to survive and would not have adequate food during——

Senator **Proxmire**. Isn't it likely that about 99 percent of that stored dairy products would disappear? I can't envision a situation in which after a nuclear war, in which that could be effectively made available.

Mr. **McLoughlin**. Certainly, there are no plans to do that today, and I acknowledge that.

The point that I make is that we have a lot of resources that are available to us.

What if we were able to do something specific and had the resources to dedicate some type of specialized storage to fuel supplies just for the sake of dealing with that kind of a maldistribution, the food problem? It is not there today.

We have strategic oil reserves in this country. There are, you know, the idea of generators, if power is not available, you know, emergency generators, is a normal one in the emergency environment.

We believe there are a number of things that could, indeed, be done to increase the preparedness and increase the survival of people.

But I acknowledge the fact that they are not being done today.

Senator **Proxmire**. Mr. McLouglin, Professor Winter says in his prepared statement that the nuclear winter findings raise serious doubts about the effectiveness of extensive programs to protect U.S.

populations and industry from large-scale nuclear war, and that in any event, a serious preparedness program would cost 10 to 100 times what is now being spent and would lead to a change in the tone of our national life. What's your answer to that?

Mr. McLoughlin. I'm sorry, Senator, I missed whom you were quoting.

Senator Proxmire. The principal part of this is a serious preparedness program that would do any good, would cost from 10 to 100 times what is now being spent and would lead to a change in the tone of our national life.

Mr. McLoughlin. Certainly we agree that it would be increased emphasis over what we have today. The program that we proposed——

Senator Proxmire. By a factor of 10 or 100?

Mr. McLoughlin. Well, the program that we proposed that we thought was a reasonable proposal in 1982 was $4.2 billion over a 7-year period. Now what I don't understand is in terms of the $10 million or more in terms of what timeframe that is, but certainly if we are talking about $10 million within a 14–15 year time period or decade versus a year. I certainly would agree with it.

Senator Proxmire. Well, how about it, Mr. Winter? You were talking about, as I understand it, a $2 or $4 billion program every year, weren't you?

Mr. Winter. At least, yes.

Senator Proxmire. So, that it would cost that much to make it worthwhile? Do you think that's feasible? Possible to sell that to Congress?

Mr. McLoughlin. No, sir.

Senator Proxmire. Well, do you disagree then with the notion as to whether you can have any kind of an effective program to protect the population and the industry?

Mr. McLoughlin. Senator, I need to go back to our mandate.

The Congress has charged us with not asking the question of whether or not we can or can't but, with the set of resources that are made available, what kind of a program can be run to provide for incremental savings of lives in a nuclear attack environment? Given the level we have right now at $190 million, I believe that the program that we are trying to pursue will indeed provide for some life saving effort. It will not save the number of lives that we think are potentially able to be saved.

Senator Proxmire. Mr. Winter, you mentioned in your prepared statement about our food reserves in 1963. Will you discuss briefly how they came about. How they could have been used in a nuclear war. With the situation as it is today, would you recommend a new civil defense food reserve program?

Mr. Winter. The situation in 1963 was that we had very large stocks of surplus grains that had been acquired in agricultural price support programs, and if you looked at the caloric content of those grains by themselves, I think you had a figure around a year to a year and a half of nutritional support for the entire preattack population and beyond that you had the normal pipeline inventories in processing and so forth.

So, in that situation it appeared that the problem was a problem of distributing those stocks or of converting them to a more usable form in the aftermath of a nuclear attack. However, the grain price support programs no longer contribute to our food stocks, or food reserves in anything like the way they did at that time.

I'm not really up to date on the figures. My impression of the figures is somewhat less optimistic or a good less optimistic than Mr. McLoughlin's impression of the figures. But I would say this, that if we were going to have a serious civil defense program, then improving the situation with regard to the size of the food stocks and their potential distribution should be one major component of the serious civil defense program.

I want to go beyond that and come back to the remarks of Mr. McLoughlin about the food situation. He mentioned the size of the food stocks and he also mentioned the fact that it would be possible to grow crops, at least so far as soil contamination considerations were concerned. But he did not say anything that met the condition that I stated for a careful study of the problem; namely, he did not address the problem of deadlines. He didn't establish that there would be large enough food stocks to last until new food production would be available and no amount of information about the stocks is useful unless you can show that the stocks last long enough so that new production would become available in time.

When you turn to the problem of new production the thing that strikes the eye if you look at the distribution of activity in the American economy, is the fact that there are only a couple of hundred target areas at most which contain all of the country's petroleum refining capacity, that the number of potential bottleneck areas in transportation is very large, and there are numerous other resource categories of potential importance to modern agriculture where a rather small number of weapons will entirely destroy the resource category.

Now, in the light of that consideration, it seems to me that the economy is plainly vulnerable to something like a total breakdown at attack levels of a few hundred weapons or at most, say, a thousand weapons. But that attack level is not much greater than the ones that Mr. Sagan has talked about in connection with nuclear winter.

Senator **PROXMIRE**. Mr. McLoughlin, I just have two or three more questions for you gentlemen, and I want to thank you very much for being so patient.

Professor Winter says, Mr. McLoughlin, that we had in effect a much more meaningful civil defense program in 1963. He referred to that when there were surplus grains and widely dispersed storage under Federal price support programs which had the equivalent of minimum nutritional support for our entire population for a period of about 2 years. Such a reserve would be essential in the event of a nuclear winter yet you don't seem to be proposing one. Isn't that an oversight?

Mr. **McLOUGHLIN**. Senator, the program in 1963 had a different character than the one has today. The program in 1963 dealt with in-place fallout protection. We essentially did—the program did not provide at all for people that were in the major risk areas. It dealt only with the fallout question essentially.

You may remember that we stocked a great number of facilities at that point with food supplies for about 4 years. We used up the excess capacity in the biscuit industry in the country with the survival crackers. We stocked water. We stocked medicine. We stocked radiological equipment and we stocked sanitation kits.

One of the things that we learned subsequent to that and as we understood the problem better and let me give you just a couple of examples. With the water problem, we stored water. We soon found out that that probably was not an appropriate thing to do. That there is a lot of trapped water in a building and making provision for recovery of that. It may make more sense to provide for emergency generators on existing water supplies, since the water supply is not likely to be contaminated, and even if it is, most of the filtration systems and most of the exchange mechanisms do indeed provide 90 some odd percent removal of that.

In the food area, we have felt that it is not appropriate, and certainly we do not have the resources and have not proposed it, to deal with the food problem by stocking shelters in the same way. We've acknowledged the fact that there are stored foods and our supply of that surplus varies from year to year.

We do not have—and I've acknowledged that—we do not have a good way of dealing with that right now.

Senator **Proxmire**. The thrust of my question was with respect to the surplus grain program. We had and continue to have big production of grain. The price has dropped sharply, as you know, but we don't have the kind of widespread dispersion that we had in 1963 or the available supplies we had that would have gotten us through. Shouldn't we have that? We can do it easily.

Mr. **McLoughlin**. You mean to have the surplus?

Senator **Proxmire**. Yes, sir.

Mr. **McLoughlin**. Senator, my guess is that's a decision for the Congress rather than for us. If indeed the Congress were to decide to——

Senator **Proxmire**. Do you recommend it?

Mr. **McLoughlin**. Pardon.

Senator **Proxmire**. If you'ld recommend it it would make a difference. There are a lot of people in the Congress who would love to support that kind of a program, not having anything to do with nuclear war but because they've got a lot of farmers who vote.

Mr. **McLoughlin**. Senator, within the administration there are many other agencies that indeed would have to comment on that before our view would prevail that it would make sense to have a surplus——

Senator **Proxmire**. Well, it's a civil defense program. I'm talking about the civil defense program. Shouldn't that be affected by the availability of food?

Mr. **McLoughlin**. Yes.

Senator **Proxmire**. We are an enormously productive agricultural economy. That's the most productive element of our economy. Why not say that from a civil defense standpoint, strictly from that standpoint, the decision would be made, of course, by the President but from your standpoint it would be a big plus.

Mr. **McLoughlin**. It would be a big plus, Senator. We have not said that. But it would only be a big plus if other factors were available as well.

Senator **Proxmire**. I understand. You would have to have all kinds of other things, but at least it would be, as Mr. Winter pointed out, it would be something in that area.

Now, Mr. Winter, you say civil defense by either superpower should have no bearing on the strategic balance or on bargaining in a crisis, but civil defense could be effective in contingencies other than large scale nuclear war such as terrorist attacks. It's my judgment, the judgment of many people I think, that the most likely scenario of a nuclear war would probably not be from the Soviet Union or even a mistake, which is more likely, probably. That is, a misinterpretation of a computer or something of that kind.

It might not even be the result of a conventional war escalating but of third countries getting a proliferation of nuclear weapons, which has been predicted before and it hasn't developed but may very well develop. Under those circumstances it seems to me that civil defense might have much more relevance.

Can you explain why civil defense is irrelevant, the strategic balance, and then discuss what difference that point makes since it is relevant to contingencies other than large scale nuclear war?

Mr. **McLoughlin**. The bottom line is we should have a civil defense program.

Mr. **Winter**. I'm not sure that that is the bottom line at all.

Senator **Proxmire**. Well, why not? I'm talking about a civil defense program not just for nuclear war purposes but for other purposes too.

Mr. **Winter**. From the point of view of the nuclear war situation, I think that the most likely scale of exchange between the Soviet Union and the United States is a scale sufficiently large to destroy those societies.

Senator **Proxmire**. I'd agree wholeheartedly but——

Mr. **Winter**. And I do not——

Senator **Proxmire**. Mr. Winter, isn't it also likely that there could be a—it's more likely that a nuclear war could develop that would not involve an exchange between the superpowers.

Mr. **Winter**. I agree that there are a range of contingencies, including, as you say, the possibility of attacks by other countries. Possibly irrational attacks by other countries.

Senator **Proxmire**. Terrorist attacks.

Mr. **Winter**. Terrorist attacks, yes, and in those circumstances——

Senator **Proxmire**. Let me just give you one hypothesis that really haunts me.

We meet in the House of Representatives, as you know, every January to hear a joint address by the President of the United States. He has the Vice President and Speaker sitting behind him. He has within 10 feet of him the entire Cabinet on one side; the entire Supreme Court on the other, 10 or 20 feet. He has the Joint Chiefs of Staff. He has the entire House and Senate and the diplomatic corps.

Any kind of a nuclear device exploded within a half mile of the Capitol would decapitate this Government and with the advance of nuclear technology that seems to me to be a real possibility.

Mr. **Winter**. I agree. I think there is a wide range of dangers of that kind and I think there would be a point to civil defense preparations for contingencies of that sort, which in general involve at most a few weapons exploding in the United States. And I would probably be eager to support a proposal for a civil defense program of that kind provided that the proposal came forward in the context of a full and explicit recognition that that program was not going to protect us very much from large scale nuclear war.

I think it is not going to protect us very much from large scale nuclear war and it's important for everybody to understand that.

Senator **Proxmire**. Doesn't it seem contradictory then, in view of that judgment, that this country has such a one dimensional civil defense program? Assumptions that they be prepared for a nuclear exchange between the Soviet Union and the United States? Do you think that's the one scenario, or one of the scenarios at least, the principal scenario, you would rule out?

Mr. **Winter**. That's correct.

Senator **Proxmire**. On the other hand, we don't seem to have a civil defense program to deal with these other—what I think are more likely circumstances in which a civil defense program could obviously be useful.

Mr. **Winter**. I agree.

Senator **Proxmire**. You want to answer that, Mr. McLoughlin?

Mr. **McLoughlin**. Senator, I'm not sure exactly of the thrust of your question at the moment.

Senator **Proxmire**. Well, the thrust of my question——

Mr. **McLoughlin**. If it's a decapitation attack we view that as a government issue principally rather than a civil defense issue, which is essentially saving lives of people. Now, I'm not suggesting that saving lives of the Congress and the executive branch is not saving lives of people, by any means, but what I'm having difficulty with is the context of your question.

If it has to do with a terrorist attack that decapitates our Government, that's essentially a continuity of a government problem as opposed to a civil defense problem as we are approaching it.

Senator **Proxmire**. Well, obviously any attack like that would have a devastating affect on Washington, even if it were one nuclear device set of, say, half a mile from the Capitol. It would not only devastate the Capitol but there would be at least tens of thousands of other people who would be killed and then there would be many others who would be badly injured. You would have a problem that, it seems to me, would be within your capability of designing a way to respond.

Mr. **McLoughlin**. Yes, sir; and the way to respond to that issue is indeed, if it's a bolt out of the blue, it's like a bolt out of the blue nuclear attack. There is not much you can do about it if you don't know it ahead of time. On the other hand, if the terrorists indeed are going to announce that fact that they do indeed have it and hold captives and there is a period of time in which people can do it, one of the legitimate and logical responses in effect is evacuation, assuming that there is time and however the scenario develops.

In the Washington area there are 3 million people roughly in this metropolitan area. We put in and out of this city every day

450,000 people in the period of about 2½ hours without ever having a major law enforcement kind of problem or major support from any kind of emergency services.

A sixth of our population goes in and out every day and to suggest that we could not evacuate this city in a reasonable period of time we believe is simply not consistent with the facts.

Senator PROXMIRE. Well, all right, it seems to me that the agency is obsessed with evacuation, ignoring food, water, medical attention, what you do when you get there.

Mr. MCLOUGHLIN. No, sir. I may have been because I felt that partially your line of questioning dealt with supporting that effort.

Certainly, relocation is the principal option. The generic option. You are correct in the fact that we have to deal with all of the supporting efforts. We believe, as I said, that water is not a problem. Is not a problem that's insoluble in any way.

We believe essentially that the medical problem is one of—most lives are likely to be saved by proper sanitary methods that people are not going to loose that knowledge in a nuclear attack and the sanitary procedures and the quarantining or separating of people who have infectious diseases, which can be done. The move to a protected environment does not deny us that opportunity. It's likely to be very effective in the control of diseases.

One of the things we believe also is that a wide spectrum antibiotic is likely to be the single most important and useful thing in a postattack environment. And one of the things that is known is that the vats that are used for beer, for example, will not grow those antibodies but those vats that are use in the soap industry, for example, that grow the enzymes indeed would provide that supportive of an effort.

Whether or not we could make adequate plans to use that and whether or not enough of those are outside of the high risk areas, is a question that we simply do not have answers for right now. And it is a question that—we think we've got some avenues for exploration. We intend to explore those just like——

Senator, if I have not mentioned it, we do have a major food processing study going on right now and our efforts are going to be to refine that food problem more precisely that we have at the moment. So, I would not like to put all of the emphasis on simply relocation. That is the generic option of which, though, we believe.

Senator PROXMIRE. All right, gentlemen, before ending this phase of our inquiry I should say that I will insert in the record articles and materials from several sources, including a selection from a recent book called "In the Dark" which contains statements by Carl Sagan and others explaining some of the recent scientific findings about the effects of nuclear war, and several studies published by the Journal Ambio on the aftermath of nuclear war that were alluded to this morning. Included in this special issue of Ambio in 1982 were scientific articles discussing how nuclear war could affect health problems, the atmosphere, global supplies of fresh water, the ocean echo systems, agriculturé, global food supplies, and the like.

[The information referred to for the record follows:]

PAUL R. EHRLICH
CARL SAGAN
DONALD KENNEDY
WALTER ORR ROBERTS

THE COLD AND THE DARK

The World after Nuclear War

Foreword by LEWIS THOMAS

The Conference on the Long-Term Worldwide Biological Consequences of Nuclear War

W · W · NORTON & COMPANY
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INTRODUCTION

DONALD KENNEDY

Ours is anything but a happy subject: In the first place, the consequences of nuclear war are dire indeed, and it is no great pleasure to tell people that they are even more dire than they have been told. Furthermore, there is unfortunately no *simple* way out of the problems posed for us by nuclear arms—though some people insist that there is. Instead, there is a continuing need to deal with danger, and to struggle with a national security policy that seems terribly refractory to logical design. It is against this depressing background that we discuss the long-range biological consequences of nuclear war.

Before beginning, I want to acquaint you with some qualifications I lack for my role of introducer, and then announce one or two convictions. I am not a veteran of the anti-nuclear movement, nor am I experienced in matters of arms control and disarmament. I am, moreover, happy to concede to others technical mastery of the inexact discipline of nuclear strategy—the technological and game-theoretic background of détente. As to convictions, I must tell you that I hold the old-fashioned belief that we shall continue to require a defense establishment in this country, that whether we like it or not nuclear weapons will continue for some time to play an integral role in our national security strategy and that of others, and that accordingly we shall need to continue efforts to understand such weapons if we are ultimately to control them and deal sensibly with one another.

These disclosures should convince you, I think, that I am neither a likely technical resource for an arms control conference nor a promising candidate for cheerleader at a peace rally. This volume is meant to reflect neither of those purposes. Rather, it is a report of some serious scientific analyses of the consequences of nuclear war. And to introduce *that* subject, I have a perspective that I think may be relevant. During a period of service in government, I was head of a federal regulatory agency much concerned with the hazards associated with toxic chemicals, and more generally with the consequences of premature introduction of new technologies. During those years, and in the time immediately preceding and following them, I found myself deeply involved in the business of risk assessment: evaluating the consequences of the use of agricultural chemicals, setting tolerances for contamination by industrial pollutants, estimating the effect of food additives, and so forth. In that role I worried a good deal about how to estimate risks, even under circumstances in which the data are necessarily incomplete.

I think three lessons from that experience are applicable to the subject under discussion. First, one of the great policy challenges in risk evaluation is to formulate the soundest possible decisions in the face of large uncertainties. To meet it successfully, it is essential that one be as aware of what one does not know as one is of what one knows.

That challenge is made enormously more difficult by public attitudes about risk. That is the second lesson: people are ambivalent about risk. We will devote enormous personal and social resources to the saving of an identified life in danger, but we will appropriate very much less to confer a statistically much larger protection upon unidentified individuals in the general population. We will enthusiastically pass laws that avert very small, involuntary risks; but we will quickly repeal them if they curtail personal freedoms. In short, we will spend a great deal to get little Kathy out of the well she has fallen into, but we have trouble lowering the speed limit, or even banning some cancer-causing substances if people like them enough.

The ambivalence becomes even more marked when probability and severity of risks are considered separately. There is a difference between attitudes toward modest, broadly distributed statistical risks, like extra cancer deaths due to an environmental toxin, and low-probability risks with widespread disastrous consequences, like a nuclear weapons exchange. Although we are only beginning to develop a science of human attitudes about risk-aversion,[1] the results so far suggest that people treat low-probability events with highly negative consequences in a way that departs significantly from the choices we would predict under standard "expected utility" theories. Such research may eventually have something quite useful to say about public attitudes on nuclear war. And it may be even *more* important with respect to the crucial matter of how the decision-makers, in those awful last moments, will be making their decisions.

The third and final lesson I should like to take from the more conventional domain of risk assessment has to do with the time scale on which we recognize consequences. Here the analogy from the world of toxic substances is actually quite exact.

When the postwar revolution in industrial chemistry first began to generate concern about the human risks associated with toxic substances, the worry was almost entirely confined to immediate or "acute" effects. The first toxicological testing programs devised to evaluate these hazards were the so-called LD$_{50}$ tests, which measured the amount of some compound that would constitute a lethal dose for 50 percent of the organisms used in the test. Later on, it was gradually recognized that long-term, "chronic" effects—the potential to cause cancer, or to make a person more prone to heart disease and stroke, or to produce birth defects—were substantially more important, and quite impossible to measure using the conventional short-term tests. Subsequent experience has confirmed that these chronic hazards are much larger worries than the acute ones, and today we would not even consider evaluating the safety of a new chemical without undertaking long-term experiments to evaluate its carcinogenic potential, its fetal effects, and so on.

That is where we now stand with respect to nuclear war: We are just beginning to understand the long-term effects—the environmental equivalents of cancer, heart disease, and stroke.

I now want to turn to a central theme in the development of our knowledge about these chronic consequences of nuclear war—*it is the erratic and accidental character of our discoveries.* What we now understand, and it is certainly much less than we wish we understood, we have come to know largely as a result of unplanned revelation, not systematic study. As a result of the weapons detonated over Japanese cities at the end of World War II, we came to a grim reckoning of acute effects—the devastation caused by the primary blast and by shock waves, and the impact of local radioactivity on humans. But it was not until the tests at Bikini Atoll in 1954 that we learned of the dangers of distant contamination by radioactive fallout following atmospheric transport. Even now, nearly three decades later, we find ourselves surprised by the significance and range of this phenomenon. For example, the celebrated escape of radiation from the damaged reactor at Three Mile Island—an incident that generated widespread concern and hundreds of pages of congressional testimony—deposited less than one-tenth the amount of radiation (as ^{131}I) that had been deposited in the same part of Pennsylvania by fallout from the cloud produced by a single bomb test in China two years earlier.[2] Other delayed and accidental revelations have included the Van Allen belt effects, the electromagnetic pulse (EMP) and its effects on electronic communications, and, more recently, the injection of NO_x (nitrogen oxides) into the ozone layer. In reviewing these events, one observer commented as follows: "Uncertainty is one of the major conclusions . . . as the haphazard and unpredicted derivation of many of our discoveries emphasizes."[3] Those words were not written by an academic critic of government policy; they came from a present undersecretary of defense in the Reagan administration.

The conclusion is clear, and it is not very comforting. We must learn to expect the unexpected. This Conference places us squarely in the midst of another and even more significant set of revelations about the chronic risks associated with nuclear war. In an important sense, the genealogy of this Conference begins with the extraordinary work of the organization called Physicians for Social Responsibility. They made the first quantitative evaluations of the medical circumstances that would prevail immediately following a nuclear exchange and demonstrated the inadequacy of present medical institutions, programs, and plans to deal with those circumstances. Their revelations raised serious questions about the entire structure of civil defense preparedness and cast grave doubt over the confident assertions of defense planners that recovery following a nuclear attack could be complete in a relatively small number of years.

The results presented at this Conference summarize more serious scientific analyses of the long-range ecological and climatological consequences of nuclear weapons exchanges. Ecological risks, in particular, were originally given remarkably short shrift in the evaluation of nuclear strategies. Early studies done under Department of Defense support (for example, that by Mitchell[4]) consisted of little more than analogies with natural catastrophes. The summary conclusion from Mitchell's Rand study will illustrate the genre: "The large-scale damage due to fire, drought, flood and other things has already presented the world with problems of reconstruction and reconstitution of biotic communities which are similar to those envisioned in the post-attack environment." How that similarity might provide a useful assessment of real risks is left to the reader.

It is, of course, not entirely fair to blame these earlier studies; our present view has become both more explicit and more somber, for a variety of reasons. First, some specific recent discoveries (for example, the sensitivity of some natural ecosystems to acid rain, and the particular sensitivity of plants to radioactivity and temperature) have tended to worsen the estimates. Second, our general view of the complexity and delicacy of ecological systems has changed a great deal over the past two decades; we now understand their vulnerability in a much more thorough way. Finally, the numbers and the accuracy of our weapons systems have changed in ways that may increase the highly destructive character of weapons exchanges.

How perplexing it is, then, that even today we are being offered reassurances based upon much earlier estimates. A pamphlet still being distributed by emergency agencies was prepared in 1979 by the Defense Civil Preparedness Agency. In it, the following conclusion appears, precisely echoing the metaphor of the 1963 report: "No logical weight of nuclear attack could induce gross changes in the balance of nature that approach in type or degree the ones that human civilization has already produced."[5] Even if it were true that the magnitude of ecological change that could result from the largest plausible nuclear attack is less than that produced by human civilization over all of history, there is surely a vast difference between the impact of large changes wrought in milliseconds and ones accomplished over millennia.

Elsewhere, the same pamphlet quotes from a 1963 National Academy of Sciences study the comforting news that "ecological imbalances that would make normal life impossible are not to be expected." There is no mention whatever of a much more recent National Academy of Sciences study on the long-term worldwide effects of multiple nuclear weapons detonations. This latter report was issued in 1975, four years *before* the disaster agency's pamphlet was prepared. Its conclusions are much harsher, as one might expect: The effects of oxides of nitrogen on the ozone layer had been recognized, and the prospects for climatic change had been taken more seriously into account. Yet the government, in accounting to its own citizens, bypassed the more recent information to provide false reassurance from an outdated source. We ought to worry whenever obsolete data are being used to inform public policy choices.

By themselves, the Academy's ecological estimates give substantial cause for greater concern. But I think it is fair to say that the most striking new information presented at this Conference, and indeed the most potentially disturbing of all of the chronic effects of nuclear war so far described, is the prospect of major climatic consequences. Those consequences are so profound that they could dwarf all of the other long-range effects heretofore known.

This new view results in part from a new general paradigm in scientific thinking about the processes that have influenced Earth's history and shaped its present form. In the eighteenth and early nineteenth centuries, major land forms were thought to have resulted from catastrophic processes, visited upon Earth and its occupants by an angry Maker. A major revolution against this view, led by the British geologist Charles Lyell, recognized the importance of such gradual processes as erosion, sedimentation, and reef-building and substituted for the catastrophist view one based upon a doctrine of uniformitarianism. Today the earth sciences are in the middle of a second revolution, triggered by the remarkable discoveries of plate tectonics, and the emphasis has moved back toward more dramatic events. Increasingly, it is recognized that major discontinuous interventions such as volcanic eruptions and asteroid collisions may have had profound effects on the history of the Earth and of the life on it. A particularly enticing hypothesis, for example, is that an asteroid collision with the Earth 65 million years ago and the long-lived atmospheric dust cloud it produced led to climatic changes that caused the massive extinctions at the end of the Cretaceous age.[6] When it was first announced, the notion that the dinosaurs might have died in the dark evoked great skepticism from my fellow biologists, but it is now widely recognized that significant events of the same kind, while not of the same magnitude, have occurred in historic time as the result of volcanic eruptions. "Years without summer" in ancient records have been associated in time with glacial deposits of acid rain, for example, and more contemporary meteorological vagaries have been associated with eruptions like that of El Chichón, Mexico, two years ago.

Findings such as these have made us much more conscious of the sensitivity of world climate to sudden perturbations. It has been known for some time that nuclear explosions can inject dust and aerosol into long-term circulation in the upper atmosphere. Recent calculations indicate that large-scale fires will add a synergistic effect, supplying additional particulates and adding substantially to the convective forces that distribute material into the circulation of the upper atmosphere. This new information has made real for the very first time the prospect that changes in temperature and ambient light, lasting for several seasons in the Northern Hemisphere, could result from a major nuclear exchange. It is a prospect of alarming magnitude.

Taken together, all this information *should* signal a major shift in the way in which we as citizens evaluate our risks, and the way in which our national strategists should view them. No longer is it acceptable to think of the *sequelae* of nuclear war in terms of minutes, days, or even months. That would be like evaluating a toxic chemical, in this day and age, in terms of what it did to one after five minutes. What we have learned from the things biologists and atmospheric physicists are telling us today is that the proper time scale is *years*, and that the processes to which we must look are unfamiliar both in kind and in scale. The risk estimates on which our strategists have been working and citing to our citizens are grossly optimistic.

I want to turn before closing to one other aspect of risk analysis. It is one I mentioned briefly earlier: the notion of "rationality" on the part of decision-makers in confronting questions of probability and severity of risk. Not only are there reasons to doubt that decisionmakers confronted with risks of great severity and low probability behave according to rational, utilitarian models of choice, but there are also explicit historical precedents for believing that they are going to behave in more political—and human—ways than the "rational actor" model would suggest. In his splendid book *The Essence of Decision,*[7] Graham Allison looks at the management by the United States government of the Cuban missile crisis in 1962 from the perspective of different behavioral models. On reading it, one cannot escape the conclusion that no chief of state, no government official, no senior military officer behaves like a "rational actor" in making decisions when the fate of nations and the world hangs in the balance. Bureaucratic structures, political allegiances, and background—as well as the other behavioral nonlinearities we are just beginning to probe—play large roles. Yet the structure of military preparedness and the strategic balance are built on the expectation of rational response and rational counter-response. Rationality will be especially hard to conserve in the early stages of a nuclear conflict, where uncertainty and the need for rapid decisions dominate. That is why it seems so unlikely to experienced military leaders as well as to others that a nuclear war can ever remain limited.

Risk assessment ought to proceed, in any event, under worst-case assumptions. That is why the scenarios used by the panels in this Conference, like most others, involve the detonation of substantial proportions of the world's nuclear stockpile. But there is an additional reason as well, and that is the likelihood that, in the real decisionmaking context of nuclear combat, it will be so difficult to confine retaliation and response that the *expected course* of such a conflict is to proceed without limit.

I want, finally, to specify what is new and what is not in this volume. It is highly significant that a large group of distinguished biologists has reached a thoughtful consensus on the ecological consequences of nuclear war. (You may not know how difficult it is for biologists, *especially* distinguished ones, to agree on anything.) The group working on atmospheric and climatic effects, in its companion report, raises some new and chilling possibilities with respect to these aspects of a nuclear aftermath. But as I have tried to illustrate, these findings are part of an orderly process in the evolution of scientific thought, through which we have gradually refocused our attention from the immediate and obvious to the more long-term and complex *sequelae.* That transition also moves us into a zone in which the effects are potentially even more serious, yet much more difficult to estimate with accuracy. Indeed, the history of our development of nuclear knowledge and the complexity of many of the longer-range effects that will be discussed here suggest that uncertainty ought to be a thematic warning to the policy planners. What our most thoughtful projections show is that a major nuclear exchange will produce, among its many plausible effects, the greatest biological and physical disruptions of this planet in its last 65 million years—a period more than 30 thousand times longer than the time that has elapsed since the birth of Christ, and more than 100 times the life span of our species so far. That assessment of prospective risk needs to form a background for everyone who bears responsibility for national security decisions, here and elsewhere.

Just as there is continuity between today's findings and the outcomes of earlier scientific work, I would emphasize that there is continuity also between the views of the scientists presented here and those of their distinguished colleagues who are not represented in this volume. I want to close by stressing the latter, since it is sometimes so easy to dismiss bad news by mistrusting the messenger. Earlier projections of the long-range effects of nuclear war, based on then-available information, were made in 1975 by the National Academy of Sciences, and in 1979 by the Congressional Office of Technology Assessment. The Academy, which was chartered by Abraham Lincoln to give advice to the United States government on scientific matters, consists of nearly thirteen hundred of America's most distinguished scientists. In addition to the 1975 study on long-term effects, it now has under way an analysis of atmospheric and climatic consequences, which we all hope will extend and draw further attention to the problems to be described at this Conference by Dr. Sagan. As a consequence of such efforts, the membership of the Academy, a year ago this past April, passed an unprecedented resolution—unprece-

APPENDIX

NUCLEAR WINTER: GLOBAL CONSEQUENCES OF MULTIPLE NUCLEAR EXPLOSIONS

R. P. Turco, O. B. Toon, T. P. Ackerman,
J. B. Pollack, and Carl Sagan

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Concern has been raised over the short- and long-term consequences of the dust, smoke, radioactivity, and toxic vapors that would be generated by a nuclear war.[1-7] The discovery that dense clouds of soil particles may have played a major role in past mass extinctions of life on Earth[8-10] has encouraged the reconsideration of nuclear war effects. Also, Crutzen and Birks[7] recently suggested that massive fires ignited by nuclear explosions could generate quantities of sooty smoke that would attenuate sunlight and perturb the climate. These developments have led us to calculate, using new data and improved models, the potential global environmental effects of dust and smoke clouds (henceforth referred to as nuclear dust and nuclear smoke) generated in a nuclear war.[11] We neglect the short-term effects of blast, fire, and radiation.[12-14] Most of the world's population could probably survive the initial nuclear exchange and would inherit the postwar environment. Accordingly, the longer-term and global-scale aftereffects of nuclear war might prove to be as important as the immediate consequences of the war.

To study these phenomena, we used a series of physical models: a nuclear war scenario model, a particle microphysics model, and a radiative-convective model. The nuclear war scenario model specifies the altitude-dependent dust, smoke, radioactivity, and NO_x injections for each explosion in a nuclear exchange (assuming the size, number, and type of detonations, including heights of burst, geographic locales, and fission yield fractions). The source model parameterization is discussed below and in a more detailed report.[15] The one-dimensional microphysical model[15-17] predicts the temporal evolution of dust and smoke clouds, which are taken to be rapidly and uniformly dispersed. The one-dimensional radiative-convective model (1-D RCM) uses the calculated dust and smoke particle size distributions and optical constants and Mie theory to calculate visible and infrared optical properties, light fluxes, and air temperatures as a function of time and height. Because the calculated air temperatures are sensitive to surface heat capacities, separate simulations are performed for land and ocean environments, to define possible temperature contrasts. The techniques used in our 1-D RCM calculations are well documented.[15,18]

Although the models we used can provide rough estimates of the average effects of widespread dust and smoke clouds, they cannot accurately forecast short-term or local effects. The applicability of our results depends on the rate and extent of dispersion of the explosion clouds and fire plumes. Soon after a large nuclear exchange, thousands of individual dust and smoke clouds would be distributed throughout the northern midlatitudes and at altitudes up to 30 km. Horizontal turbulent diffusion, vertical wind shear, and continuing smoke emission could spread the clouds of nuclear debris over the entire zone, and tend to fill in any holes in the clouds, within 1 to 2 weeks. Spatially averaged simulations of this initial period of cloud spreading must be viewed with caution; effects would be smaller at some locations and larger at others, and would be highly variable with time at any given location.

The present results also do not reflect the strong coupling between atmospheric motions on all length scales and the modified atmospheric solar and infrared heating and cooling rates computed with the 1-D RCM. Global circulation patterns would almost certainly be altered in response to the large disturbances in the driving forces calculated here.[19] Although the 1-D RCM can predict only horizontally, diurnally, and seasonally averaged conditions, it is capable of estimating the first-order climate responses of the atmosphere, which is our intention in this study.

Scenarios

A review of the world's nuclear arsenals[20-24] shows that the primary strategic and theater weapons amount to $\simeq$ 12,000 megatons (MT) of yield carried by $\simeq$ 17,000 warheads. These arsenals are roughly equivalent in explosive power to 1 million Hiroshima bombs. Although the total number of high-yield warheads is declining with time, about 7,000 MT is still accounted for by warheads of $>$ 1 MT. There are also $\simeq$ 30,000 lower-yield tactical warheads and munitions which are ignored in this analysis. Scenarios for the possible use of nuclear weapons are complex and controversial. Historically, studies of the long-term effects of nuclear war have focused on a full-scale exchange in the range of 5,000 to 10,000 MT.[2,11,20] Such exchanges are possible, given the current arsenals and the unpredictable nature of warfare, particularly nuclear warfare, in which escalating massive exchanges could occur.[25]

An outline of the scenarios adopted here is presented in Table 1. Our baseline scenario assumes an exchange of 5,000 MT. Other cases span a range of total yield from 100 to 25,000 MT. Many high-priority military and industrial assets are located near or within urban zones.[26] Accordingly, a modest fraction (15 to 30 percent) of the total yield is assigned to urban or industrial targets. Because of the large yields of strategic warheads (generally $\geq$ 100 kilotons [KT]), "surgical" strikes against individual targets are difficult; for instance, a 100-KT airburst can level and burn an area of $\simeq$ 50 km^2, and a 1-MT airburst, $\simeq$ 5 times that area,[27,28] implying widespread collateral dam-

Table 1. Nuclear Exchange Scenarios.

Case*	Total yield (MT)	Percent of yield: Surface bursts	Percent of yield: Urban or industrial targets	Warhead yield range (MT)	Total number of explosions
1. Baseline exchange	5,000	57	20	0.1 to 10	10,400
2. Low-yield airbursts	5,000	10	33	0.1 to 1	22,500†
9. 10,000-MT‡ maximum	10,000	63	15	0.1 to 10	16,160
10. 3,000-MT exchange	3,000	50	25	0.3 to 5	5,433
11. 3,000-MT counterforce	3,000	70	0	1 to 10	2,150
12. 1,000-MT exchange§	1,000	50	25	0.2 to 1	2,250
13. 300-MT Southern Hemisphere‖	300	0	50	1.	300
14. 100-MT city attack¶	100	0	100	0.1	1,000
16. Silos, "severe" case#	5,000	100	0	5 to 10	700
18. 25,000-MT‡ "future war"	25,000	72	10	0.1 to 10	28,300†

*Case numbers correspond to a complete list given in Ref. 15. Detailed detonation inventories are not reproduced here. Except as noted, attacks are concentrated in the NH. Baseline dust and smoke parameters are described in Tables 2 and 3. †Assumes more extensive MIRVing of existing missiles and some possible new deployment of medium- and long-range missiles.[20-23] ‡Although these larger total yields might imply involvement of the entire globe in the war, for ease of comparison hemispherically averaged results are still considered. §Nominal area of wildfires is reduced from 5×10^5 to 5×10^4 km^2. ‖Nominal area of wildfires is reduced from 5×10^5 to 5×10^3 km^2. ¶The central city burden of combustibles is 20 g/cm^2 (twice that in the baseline case) and the net fire smoke emission is 0.026 g per gram of material burned. There is a negligible contribution to the opacity from wildfires and dust. #Includes a sixfold increase in the fine dust mass lofted per megaton of yield.

age in any "countervalue," and many "counterforce," detonations.

The properties of nuclear dust and smoke are critical to the present analysis. The basic parameterizations are described in Tables 2 and 3, respectively; details may be found in Ref. 15. For each explosion scenario, the fundamental quantities that must be known to make optical and climate predictions are the total atmospheric injections of fine dust ($\leq$ 10 μm in radius) and soot.

Nuclear explosions at or near the ground can generate fine particles by several mechanisms[27]: (i) ejection and disaggregation of soil particles,[29] (ii) vaporization and renucleation of earth and rock,[30] and (iii) blowoff and sweepup of surface dust and smoke.[31] Analyses of nuclear test data indicate that roughly 1×10^5 to 6×10^5 tons of dust per megaton of explosive yield are held in the stabilized clouds of land surface detonations.[32] Moreover, size analysis of dust samples collected in nuclear clouds indicates a substantial submicrometer fraction.[33] Nuclear surface detonations may be much more

Table 2. Dust Parameterization for the Baseline Case.

Type of burst	Dust mass (ton/MT):	Dust size distribution† $[r_m(\mu m)/\sigma/\alpha]$:	H_2O (ton/MT):
	*Materials in stabilized nuclear explosion clouds**		
Land surface	3.3×10^5	0.25/2.0/4.0	1.0×10^5
Land near-surface	1.0×10^5	0.25/2.0/4.0	1.0×10^5

Dust composition: siliceous minerals and glasses

Index of refraction at visible wavelengths‡: $n = 1.50 - 0.001\, i$

Stabilized nuclear cloud top and bottom heights, z_t and z_b, for surface and low-air bursts§: $z_t = 21\ Y^{0.2}$; $z_b = 13\ Y^{0.2}$; where Y = yield in megatons

Multiburst interactions are ignored

Baseline dust injections

Total dust $\simeq 9.6 \times 10^8$ tons; 80 percent in the stratosphere; 8.4 percent < 1 μm in radius

Submicrometer dust injection is ~ 25 ton/KT for surface bursts, which represents ~ 0.5 percent of the total ejecta mass

Total initial area of stabilized fireballs $\simeq 2.0 \times 10^6$ km²

*Materials are assumed to be uniformly distributed in the clouds. †Particle size distributions (number/cm³ – μm radius) are log-normal with a power-law tail at large sizes. The parameters r_m and σ are the log-normal number mode radius and size variance, respectively, and α is the exponent of the $r^{-\alpha}$ dependence at large sizes. The log-normal and power-law distributions are connected at a radius of $\cong$ 1 μm.[15] ‡The refractive indices of dust at infrared wavelengths are discussed in Ref. 10. §The model of Foley and Ruderman[87] is adopted, but with the cloud heights lowered by about 0.5 km. The original cloud heights are based on U.S. Pacific test data, and may overestimate the heights at midlatitudes by several kilometers.

Table 3. Fire and Smoke Parameterization for the Baseline Case.

Fire area and emissions

Area of urban fire ignition defined by the 20 cal/cm^2 thermal irradiance contour ($\simeq$ 5 psi peak overpressure contour) with an average atmospheric transmittance of 50 percent: A (km^2)$=250\ Y$, where Y = yield in megatons detonated over cities; overlap of fire zones is ignored

Urban flammable material burdens average 3 g/cm^2 in suburban areas and 10 g/cm^2 in city centers (5 percent of the total urban area)

Average consumption of flammables in urban fires is 1.9 g/cm^2

Average net smoke emission factor is 0.027 g per gram of material burned (for urban centers it is only 0.011 g/g)

Area of wildfires is 5×10^5 km^2 with 0.5 g/cm^2 of fuel burned, and a smoke emission factor of 0.032 g/g

Long-term fires burn 3×10^{14} g of fuel with an emission factor of 0.05 g/g

Fire plume heights (top and bottom altitudes)

Urban fires: 1 to 7 km

Firestorms (5 percent of urban fires): $z_b \leq 5$ km; $z_t \leq 19$ km

Wildfires: 1 to 5 km

Long-term fires: 0 to 2 km

Fire duration

Urban fires, 1 day; wildfires, 10 days; long-term fires, 30 days

Smoke properties

Density, 1.0 g/cm^3; complex index of refraction, $1.75-0.30\,i$; size distribution, log-normal with $r_m(\mu\text{m})/\sigma=0.1/2.0$ for urban fires and 0.05/2.0 for wildfires and long-term fires

Baseline smoke injections

Total smoke emission = 2.25×10^8 tons, 5 percent in the stratosphere

Urban-suburban fires account for 52 percent of emissions, firestorms for 7 percent, wildfires for 34 percent, and long-term fires for 7 percent

Total area burned by urban-suburban fires is 2.3×10^5 km^2; firestorms, 1.2×10^4 km^2; and wildfires, 5.0×10^5 km^2

efficient in generating fine dust than volcanic eruptions,[15,34] which have been used inappropriately in the past to estimate the impacts of nuclear war.[2]

The intense light emitted by a nuclear fireball is sufficient to ignite flammable materials over a wide area.[33] The explosions over Hiroshima and Nagasaki both initiated massive conflagrations.[35] In each city, the region heavily damaged by blast was also consumed by fire.[36] Assessments over the past two decades strongly suggest that widespread fires would occur after most nuclear bursts over forests and cities.[37-44] The Northern Hemisphere has $\simeq 4\times10^7$ km^2 of forest land, which holds combustible material averaging ~ 2.2

g/cm².[7] The world's urban and suburban zones cover an area of ≃ 1.5 × 10^6 km².[13] Central cities, which occupy 5 to 10 percent of the total urban area, hold ≃ 10 to 40 g/cm² of combustible material, while residential areas hold ≃ 1 to 5 g/cm².[41,42,44,45] Smoke emissions from wildfires and large-scale urban fires probably lie in the range of 2 to 8 percent by mass of the fuel burned.[46] The highly absorbing sooty fraction (principally graphitic carbon) could comprise up to 50 percent of the emission by weight.[47,48] In wildfires, and probably urban fires, ≳ 90 percent of the smoke mass consists of particles < 1 μm in radius.[49] For calculations at visible wavelengths, smoke particles are assigned an imaginary part of the refractive index of 0.3.[50]

Simulations

The model predictions discussed here generally represent effects averaged over the Northern Hemisphere (NH). The initial nuclear explosions and fires would be largely confined[51] to northern midlatitudes (30° to 60°N). Accordingly, the predicted mean dust and smoke opacity could be larger by a factor of 2 to 3 at midlatitudes, but smaller elsewhere. Hemispherically averaged optical depths at visible wavelengths[52] for the mixed nuclear dust and smoke clouds corresponding to the scenarios in Table 1 are shown in Figure 1. The vertical optical depth is a convenient diagnostic of nuclear cloud properties and may be used roughly to scale atmospheric light levels and temperatures for the various scenarios.

In the baseline scenario (Case 1, 5,000 MT), the initial NH optical depth is ≃ 4, of which ≃ 1 is due to stratospheric dust and ≃ 3 to tropospheric smoke. After 1 month the optical depth is still ≃ 2. Beyond 2 to 3 months, dust dominates the optical effects, as the soot is largely depleted by rainout and washout.[54] In the baseline case, about 240,000 km² of urban area is partially (50 percent) burned by ≃ 1,000 MT of explosions (only 20 percent of the total exchange yield). This roughly corresponds to one-sixth of the world's urbanized land area, one-fourth of the developed area of the NH, and one-half of the area of urban centers with populations > 100,000 in the NATO and Warsaw Pact countries. The mean quantity of combustible material consumed over the burned area is ≃ 1.9 g/cm². Wildfires ignited by the remaining 4,000 MT of yield burn another 500,000 km² of forest, brush, and grasslands,[7,39,53] consuming ≃ 0.5 g/cm² of fuel in the process.[7]

Total smoke emission in the baseline case is ≃ 225 million tons (released over several days). By comparison, the current annual global smoke emission is estimated as ≃ 200 million tons,[13] but is probably < 1 percent as effective as nuclear smoke would be in perturbing the atmosphere.[54]

The optical depth simulations for Cases 1, 2, 9, and 10 in Figure 1 show that a range of exchanges between 3,000 and 10,000 MT might create similar effects. Even Cases 11, 12, and 13, while less severe in their absolute impact,

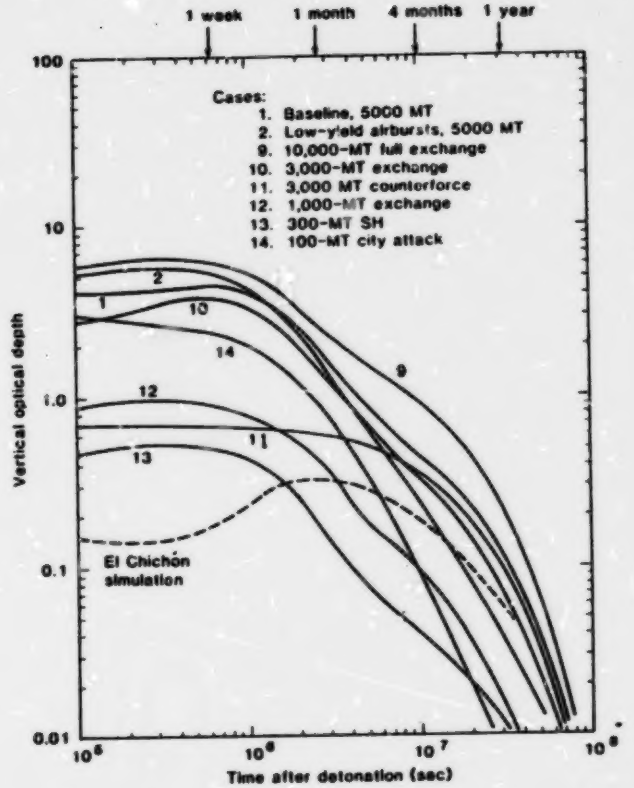

Figure 1. Time-dependent hemispherically averaged vertical optical depths (scattering plus absorption) of nuclear dust and smoke clouds at a wavelength of 550 nm. Optical depths ≤ 0.1 are negligible, ~ 1 are significant, and > 2 imply possible major consequences. Transmission of sunlight becomes highly nonlinear at optical depths ≥ 1. Results are given for several of the cases in Table 1. Calculated optical depths for the expanding El Chichón eruption cloud are shown for comparison.[63]

produce optical depths comparable to or exceeding those of a major volcanic eruption. It is noteworthy that eruptions such as Tambora in 1815 may have produced significant climate perturbations, even with an average surface temperature decrease of ≤ 1°K.[37-40]

Case 14 represents a 100-MT attack on cities with 1,000 100-KT warheads. In the attack, 25,000 km² of built-up urban area is burned (such an area could be accounted for by ≃ 100 major cities). The smoke emission is computed with fire parameters that differ from the baseline case. The average burden of combustible material in city centers is 20 g/cm^2 (versus 10 g/cm^2 in Case 1) and the average smoke emission factor is 0.026 gram of smoke per gram of material burned (versus the conservative figure of 0.011 g/g adopted for central city fires in the baseline case). About 130 million tons of urban smoke is injected into the troposphere in each case (none reaches the stratosphere in Case 14). In the baseline case, only about 10 percent of the urban smoke originates from fires in city centers (Table 3).

The smoke injection threshold for major optical perturbations on a hemispheric scale appears to lie at ≃ 1 × 10^8 tons. From Case 14, one can envision the release of ≃ 1 × 10^6 tons of smoke from each of 100 major city fires consuming ≃ 4 × 10^7 tons of combustible material per city. Such fires could be ignited by 100 MT of nuclear explosions. Unexpectedly, less than 1 percent of the existing strategic arsenals, if targeted on cities, could produce optical (and climatic) disturbances much larger than those previously associated with a massive nuclear exchange of ≃ 10,000 MT.[3]

Figure 2 shows the surface temperature perturbation over continental land areas in the NH calculated from the dust and smoke optical depths for several scenarios. Most striking are the extremely low temperatures occurring within 3 to 4 weeks after a major exchange. In the baseline 5,000-MT case, a minimum land temperature of ≃ 250°K (−23°C) is predicted after 3 weeks. Subfreezing temperatures persist for several months. Among the cases shown,

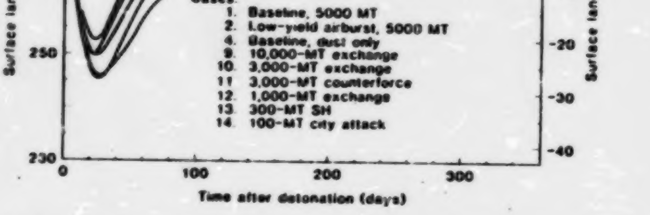

Figure 2. Hemispherically averaged surface temperature variations after a nuclear exchange. Results are shown for several of the cases in Table 1. (Note the linear time scale, unlike that in Fig. 1). Temperatures generally apply to the interior of continental land masses. Only in Cases 4 and 11 are the effects of fires neglected.

even the smallest temperature decreases on land are $\simeq$ 5° to 10°C (Cases 4, 11, and 12), enough to turn summer into winter. Thus, severe climatological consequences might be expected in each of these cases. The 100-MT city airburst scenario (Case 14) produces a 2-month interval of subfreezing land temperatures, with a minimum again near 250°K. The temperature recovery in this instance is hastened by the absorption of sunlight in optically thin remnant soot clouds (see below). Comparable exchanges with and without smoke emission (for instance, Cases 10 and 11) show that the tropospheric soot layers cause a sudden surface cooling of short duration, while fine stratospheric dust is responsible for prolonged cooling lasting a year or more. (Climatologically, a long-term surface cooling of only 1°C is significant.[40]) In all instances, nuclear dust acts to cool the Earth's surface; soot also tends to cool the surface except when the soot cloud is both optically thin and located near the surface (an unimportant case because only relatively small transient warmings $\leq$ 2°K can thereby be achieved[41]).

Predicted air temperature variations over the world's oceans associated with changes in atmospheric radiative, transport are always small (cooling of $\leq$ 3°K) because of the great heat content and rapid mixing of surface waters. However, variations in atmospheric zonal circulation patterns (see below) might significantly alter ocean currents and upwelling, as occurred on a smaller scale recently in the Eastern Pacific (El Niño).[42] The oceanic heat reservoir would also moderate the predicted continental land temperature decreases, particularly in coastal regions.[19] The effect is difficult to assess because disturbances in atmospheric circulation patterns are likely. Actual temperature decreases in continental interiors might be roughly 30 percent smaller than predicted here, and along coastlines 70 percent smaller.[10] In the baseline case, therefore, continental temperatures may fall to $\simeq$ 260° K before returning to ambient.

Predicted changes in the vertical temperature profile for the baseline nuclear exchange are illustrated as a function of time in Figure 3. The dominant features of the temperature perturbation are a large warming (up to 80°K) of the lower stratosphere and upper troposphere, and a large cooling (up to 40 °K) of the surface and lower troposphere. The warming is caused by absorption of solar radiation in the upper-level dust and smoke clouds; it persists for an extended period because of the long residence time of the particles at high altitudes. The size of the warming is due to the low heat capacity of the upper atmosphere, its small infrared emissivity, and the initially low temperatures at high altitudes. The surface cooling is the result of attenuation of the incident solar flux by the aerosol clouds (see Fig. 4) during the first month of the simulation. The greenhouse effect no longer occurs in our calculations because solar energy is deposited above the height at which infrared energy is radiated to space.

Decreases in insolation for several nuclear war scenarios are shown in Figure 4. The baseline case implies average hemispheric solar fluxes at the

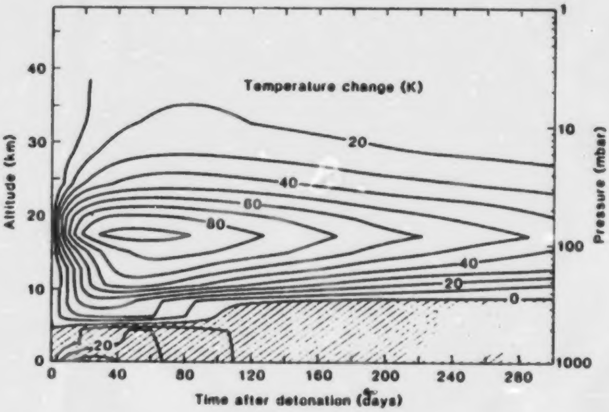

Figure 3. Northern Hemisphere troposphere and stratosphere temperature perturbations (in Kelvins; 1°K = 1°C) after the baseline nuclear exchange (Case 1). The hatched area indicates cooling. Ambient pressure levels in millibars are also given.

ground ≤ 10 percent of normal values for several weeks (apart from any patchiness in the dust and smoke clouds). In addition to causing the temperature declines mentioned above, the attenuated insolation could affect plant growth rates, and vigor in the marine,[43] littoral, and terrestrial food chains. In the 10,000-MT "severe" case, average light levels are below the minimum required for photosynthesis for about 40 days over much of the Northern Hemisphere. In a number of other cases, insolation may, for more than 2 months, fall below the compensation point at which photosynthesis is just sufficient to maintain plant metabolism. Because nuclear clouds are likely to remain patchy the first week or two after an exchange, leakage of sunlight through holes in the clouds could enhance plant growth activity above that predicted for average cloud conditions; however, soon thereafter the holes are likely to be sealed.

Sensitivity Tests

A large number of sensitivity calculations were carried out as part of this study.[15] The results are summarized here. Reasonable variations in the nuclear dust parameters in the baseline scenario produce initial hemispherically averaged dust optical depths varying from about 0.2 to 3.0. Accordingly, nuclear dust alone could have a major climatic impact. In the baseline case, the dust opacity is much greater than the total aerosol opacity associated with the El Chichón and Agung eruptions[39,64]; even when the dust parameters are

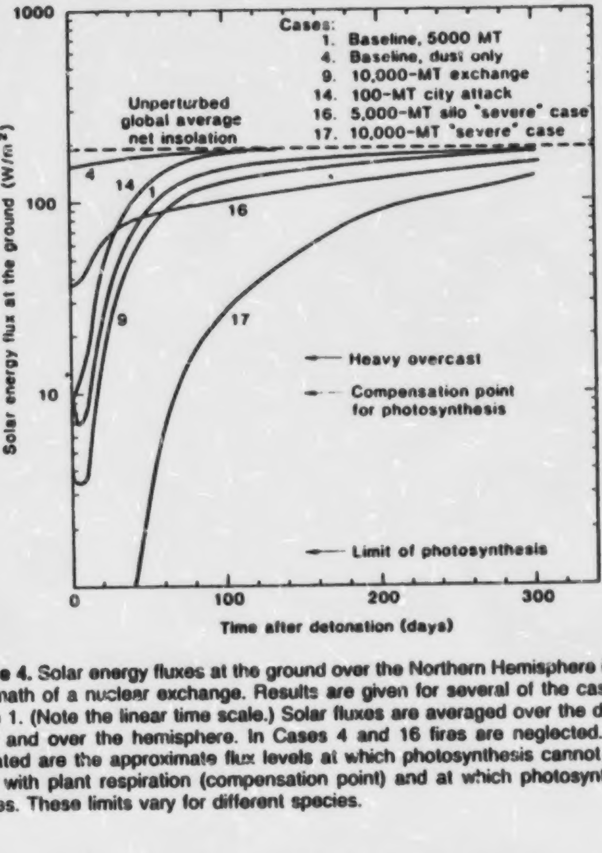

Figure 4. Solar energy fluxes at the ground over the Northern Hemisphere in the aftermath of a nuclear exchange. Results are given for several of the cases in Table 1. (Note the linear time scale.) Solar fluxes are averaged over the diurnal cycle and over the hemisphere. In Cases 4 and 16 fires are neglected. Also indicated are the approximate flux levels at which photosynthesis cannot keep pace with plant respiration (compensation point) and at which photosynthesis ceases. These limits vary for different species.

assigned their least adverse values within the plausible range, the effects are comparable to those of a major volcanic explosion.

Figure 5 compares nuclear cloud optical depths for several variations of the baseline model smoke parameters (with dust included). In the baseline case, it is assumed that firestorms inject only a small fraction ($\simeq$ 5 percent) of the total smoke emission into the stratosphere.[43] Thus, Case 1 and Case 3 (no firestorms) are very similar. As an extreme excursion, all the nuclear smoke is injected into the stratosphere and rapidly dispersed around the globe (Case 26); large optical depths can then persist for a year (Fig. 5). Prolongation of optical effects is also obtained in Case 22, where the tropospheric washout lifetime of smoke particles is increased from 10 to 30 days near the ground.

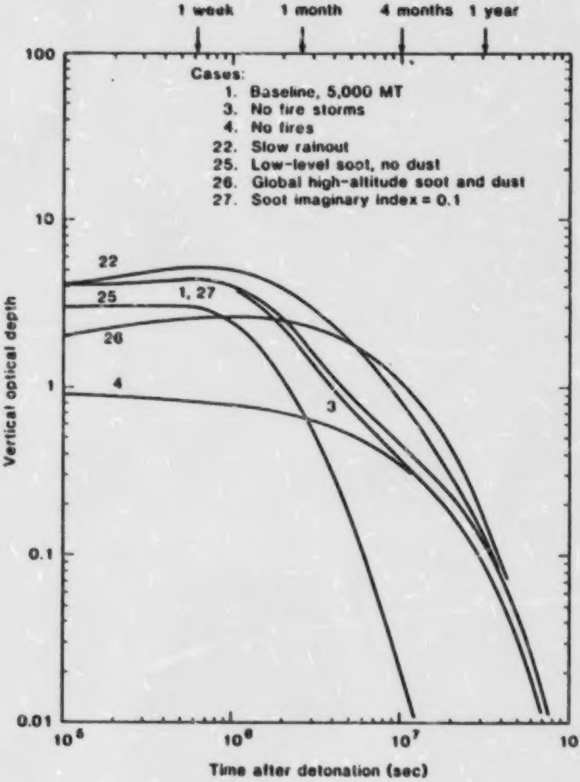

Figure 5. Time-dependent vertical optical depths (absorption plus scattering at 550 nm) of nuclear clouds, in a sensitivity analysis. Optical depths are average values for the Northern Hemisphere. All cases shown correspond to parameter variations of the baseline model (Case 1) and include dust appropriate to it: Case 3, no firestorms; Case 4, no fires; Case 22, smoke rainout rate decreased by a factor of 3; Case 25, smoke initially confined to the lowest 3 km of the atmosphere; Case 26, smoke initially distributed between 13 and 19 km over the entire globe; and Case 27, smoke imaginary part of refractive index reduced from 0.3 to 0.1. For comparison, in Case 4, only dust from the baseline model is considered (fires are ignored).

By contrast, when the nuclear smoke is initially contained near the ground and dynamical and hydrological removal processes are assumed to be unperturbed, smoke depletion occurs much faster (Case 25). But even in this case, some of the smoke still diffuses to the upper troposphere and remains there for several months.[44]

In a set of optical calculations, the imaginary refractive index of the smoke was varied between 0.3 and 0.01. The optical depths calculated for indices between 0.1 and 0.3 show virtually no differences (Cases 1 and 27 in Fig. 5). At an index of 0.05, the absorption optical depth[32] is reduced by only $\simeq$ 50 percent, and at 0.01, by $\simeq$ 85 percent. The overall opacity (absorption plus scattering), moreover, increases by $\simeq$ 5 percent. These results show that light absorption and heating in nuclear smoke clouds remain high until the graphitic carbon fraction of the smoke falls below a few percent.

One sensitivity test (Case 29, not illustrated) considers the optical effects in the Southern Hemisphere (SH) of dust and soot transported from the NH stratosphere. In this calculation, the smoke in the 300-MT SH Case 13 is combined with half the baseline stratospheric dust and smoke (to approximate rapid global dispersion in the stratosphere). The initial optical depth is $\simeq$ 1 over the SH, dropping to about 0.3 in 3 months. Predicted average SH continental surface temperatures fall by 8°K within several weeks and remain at least 4°K below normal for nearly 8 months. The seasonal influence should be taken into account, however. For example, the worst consequences for the NH might result from a spring or summer exchange, when crops are vulnerable and fire hazards are greatest. The SH, in its fall or winter, might then be least sensitive to cooling and darkening. Nevertheless, the implications of this scenario for the tropical regions in both hemispheres appear to be serious and worthy of further analysis. Seasonal factors can also modulate the atmospheric response to perturbations by smoke and dust, and should be considered.

A number of sensitivity tests for more severe cases were run with exchange yields ranging from 1,000 to 10,000 MT and smoke and dust parameters assigned more adverse, but not implausible, values. The predicted effects are substantially worse (see below). The lower probabilities of these severe cases must be weighed against the catastrophic outcomes which they imply. It would be prudent policy to assess the importance of these scenarios in terms of the product of their probabilities and the costs of their corresponding effects. Unfortunately, we are unable to give an accurate quantitative estimate of the relevant probabilities. By their very nature, however, the severe cases may be the most important to consider in the deployment of nuclear weapons.

With these reservations, we present the optical depths for some of the more severe cases in Figure 6. Large opacities can persist for a year, and land surface temperatures can fall to 230° to 240°K, about 50°K below normal. Combined with low light levels (Fig. 4), these severe scenarios raise the possibility of widespread and catastrophic ecological consequences.

Two sensitivity tests were run to determine roughly the implications for optical properties of aerosol agglomeration in the early expanding clouds. (The simulations already take into account continuous coagulation of the particles in the dispersed clouds.) Very slow dispersion of the initial stabilized dust and smoke clouds, taking nearly 8 months to cover the NH, was as-

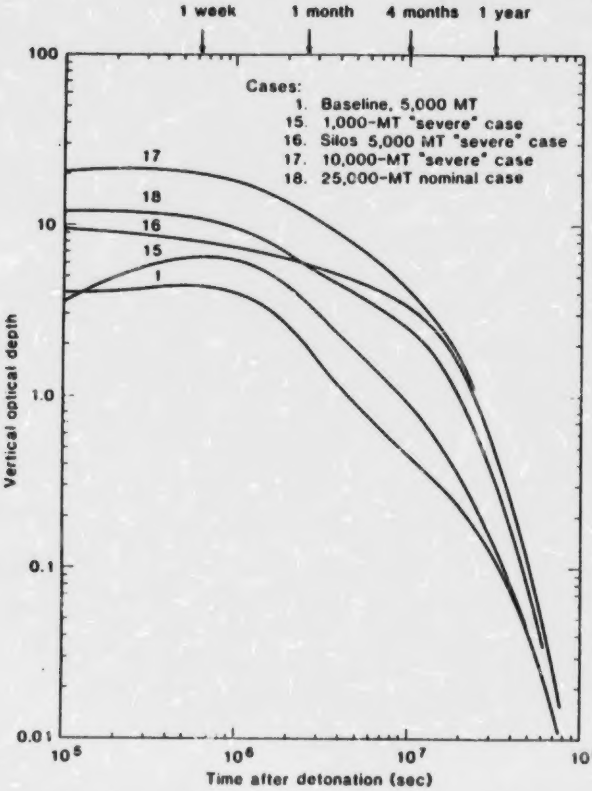

Figure 6. Time-dependent vertical optical depths (absorption plus scattering at 550 nm) for enhanced cases of explosion yield or nuclear dust and smoke production. Conditions are detailed elsewhere.[15] Weapon yield inventories are identical to the nominal cases of the same total yield described in Table 1 (Cases 16 and 18 are also listed there). The "severe" cases generally include a sixfold increase in fine dust injection and a doubling of smoke emission. In Cases 15, 17, and 18, smoke causes most of the opacity during the first 1 to 2 months. In Cases 17 and 18, dust makes a major contribution to the optical effects beyond 1 to 2 months. In Case 16, fires are neglected and dust from surface bursts produces all of the opacity.

sumed. Coagulation of particles reduced the average opacity after 3 months by about 40 percent. When the adhesion efficiency of the colliding particles was also maximized, the average opacity after 3 months was reduced by $\simeq$ 75 percent. In the most likely situation, however, prompt agglomeration and coagulation might reduce the average hemispheric cloud optical depths by 20 to 50 percent.

Other Effects

We also considered, in less detail, the long-term effects of radioactive fallout, fireball-generated NO_x, and pyrogenic toxic gases.[13] The physics of radioactive fallout is well known.[2,5,12,27,67] Our calculations bear primarily on the widespread intermediate time scale accumulation of fallout due to washout and dry deposition of dispersed nuclear dust.[68] To estimate possible exposure levels, we adopt a fission yield fraction of 0.5 for all weapons. For exposure to only the gamma emission of radioactive dust that begins to fall out after 2 days in the baseline scenario (5,000 MT), the hemispherically averaged total dose accumulated by humans over several months could be $\simeq$ 20 rads, assuming no shelter from or weathering of the dust. Fallout during this time would be confined largely to northern midlatitudes; hence the dose there could be $\simeq$ 2 to 3 times larger.[69,70] Considering ingestion of biologically active radionuclides[27,71] and occasional exposure to localized fallout, the average total chronic midlatitude dose of ionizing radiation for the baseline case could be $\geq$ 50 rads of whole-body external gamma radiation, plus $\geq$ 50 rads to specific body organs from internal beta and gamma emitters.[71,72] In a 10,000-MT exchange, under the same assumptions, these mean doses would be doubled. Such doses are roughly an order of magnitude larger than previous estimates, which neglected intermediate time scale washout and fallout of tropospheric nuclear debris from low-yield ($<$ 1-MT) detonations.

The problem of NO_x produced in the fireballs of high-yield explosions, and the resulting depletion of stratospheric ozone, has been treated in a number of studies.[2-4,7,73] In our baseline case a maximum hemispherically averaged ozone reduction of $\simeq$ 30 percent is found. This would be substantially smaller if individual warhead yields were all reduced below 1 MT. Considering the relation between solar UV-B radiation increases and ozone decreases,[74] UV-B doses roughly twice normal are expected in the first year after a baseline exchange (when the dust and soot had dissipated). Large UV-B effects could accompany exchanges involving warheads of greater yield (or large multiburst laydowns).

A variety of toxic gases (pyrotoxins) would be generated in large quantities by nuclear fires, including CO and HCN. According to Crutzen and Birks,[7] heavy air pollution, including elevated ozone concentrations, could blanket the NH for several months. We are also concerned about dioxins and furans, extremely persistent and toxic compounds which are released during the combustion of widely used synthetic organic chemicals.[75] Hundreds of tons of dioxins and furans could be generated during a nuclear exchange.[76] The long-term ecological consequences of such nuclear pyrotoxins seem worthy of further consideration.

Meteorological Perturbations

Horizontal variations in sunlight absorption in the atmosphere, and at the surface, are the fundamental drivers of atmospheric circulation. For many of the cases considered in this study, sizable changes in the driving forces are implied. For example, temperature contrasts greater than 10°K between NH continental areas and adjacent oceans may induce a strong monsoonal circulation, in some ways analogous to the wintertime pattern near the Indian subcontinent. Similarly, the temperature contrast between debris-laden atmospheric regions and adjacent regions not yet filled by smoke and dust will cause new circulation patterns.

Thick clouds of nuclear dust and smoke can thus cause significant climatic perturbations, and related effects, through a variety of mechanisms: reflection of solar radiation to space and absorption of sunlight in the upper atmosphere, leading to overall surface cooling; modification of solar absorption and heating patterns that drive the atmospheric circulation on small scales[77] and large scales[78]; introduction of excess water vapor and cloud condensation nuclei, which affect the formation of clouds and precipitation[79]; and alteration of the surface albedo by fires and soot.[80] These effects are closely coupled in determining the overall response of the atmosphere to a nuclear war.[81] It is not yet possible to forecast in detail the changes in coupled atmospheric circulation and radiation fields, and in weather and microclimates, which would accompany the massive dust and smoke injections treated here. Hence speculation must be limited to the most general considerations.

Water evaporation from the oceans is a continuing source of moisture for the marine boundary layer. A heavy semipermanent fog or haze layer might blanket large bodies of water. The consequences for marine precipitation are not clear, particularly if normal prevailing winds are greatly modified by the perturbed solar driving force. Some continental zones might be subject to continuous snowfall for several months.[10] Precipitation can lead to soot removal, although this process may not be very efficient for nuclear clouds.[77,79] It is likely that, on average, precipitation rates would be generally smaller than in the ambient atmosphere; the major remaining energy source available for storm genesis is the latent heat from ocean evaporation, and the upper atmosphere is warmer than the lower atmosphere which suppresses convection and rainfall.

Despite possible heavy snowfalls, it is unlikely that an ice age would be triggered by a nuclear war. The period of cooling ($\leq$ 1 year) is probably too short to overcome the considerable inertia in the Earth's climate system. The oceanic heat reservoir would probably force the climate toward contemporary norms in the years after a war. The CO_2 input from nuclear fires is not significant climatologically.[7]

Interhemispheric Transport

In earlier studies it was assumed that significant interhemispheric transport of nuclear debris and radioactivity requires a year or more.[7] This was based on observations of transport under ambient conditions, including dispersion of debris clouds from individual atmospheric nuclear weapons tests. However, with dense clouds of dust and smoke produced by thousands of nearly simultaneous explosions, large dynamical disturbances would be expected in the aftermath of a nuclear war. A rough analogy can be drawn with the evolution of global-scale dust storms on Mars. The lower martian atmosphere is similar in density to the Earth's stratosphere, and the period of rotation is almost identical to the Earth's (although the solar insolation is only half the terrestrial value). Dust storms that develop in one hemisphere on Mars often rapidly intensify and spread over the entire planet, crossing the equator in a mean time of ≃ 10 days.[15,82,83] The explanation apparently lies in the heating of the dust aloft, which then dominates other heat sources and drives the circulation. Haberle *et al.*[82] used a two-dimensional model to simulate the evolution of martian dust storms and found that dust at low latitudes, in the core of the Hadley circulation, is the most important in modifying the winds. In a nuclear exchange, most of the dust and smoke would be injected at middle latitudes. However, Haberle *et al.*[82] could not treat planetary-scale waves in their calculations. Perturbations of planetary wave amplitudes may be critical in the transport of nuclear war debris between middle and low latitudes.

Significant atmospheric effects in the SH could be produced (i) through dust and smoke injection resulting from explosions on SH targets, (ii) through transport of NH debris across the meteorological equator by monsoon-like winds,[84] and (iii) through interhemispheric transport in the upper troposphere and stratosphere, driven by solar heating of nuclear dust and smoke clouds. Photometric observations of the El Chichón volcanic eruption cloud (origin, 14°N) by the Solar Mesophere Explorer satellite show that 10 to 20 percent of the stratospheric aerosol had been transported to the SH after ≃ 7 weeks.[85]

Discussion and Conclusions

The studies outlined here suggest severe long-term climatic effects from a 5,000-MT nuclear exchange. Despite uncertainties in the amounts and properties of the dust and smoke produced by nuclear detonations, and the limitations of models available for analysis, the following tentative conclusions may be drawn.

(1) Unlike most earlier studies (for instance, Ref. 2), we find that a global nuclear war could have a major impact on climate—manifested by significant surface darkening over many weeks, subfreezing land temperatures persisting for up to several months, large perturbations in global circulation patterns,

and dramatic changes in local weather and precipitation rates—a harsh "nuclear winter" in any season. Greatly accelerated interhemispheric transport of nuclear debris in the stratosphere might also occur, although modeling studies are needed to quantify this effect. With rapid interhemispheric mixing, the SH could be subjected to large injections of nuclear debris soon after an exchange in the Northern Hemisphere. In the past, SH effects have been assumed to be minor. Although the climate disturbances are expected to last more than a year, it seems unlikely that a major long-term climatic change, such as an ice age, would be triggered.

(2) Relatively large climatic effects could result even from relatively small nuclear exchanges (100 to 1,000 MT) if urban areas were heavily targeted, because as little as 100 MT is sufficient to devastate and burn several hundred of the world's major urban centers. Such a low threshold yield for massive smoke emissions, although scenario-dependent, implies that even limited nuclear exchanges could trigger severe aftereffects. It is much less likely that a 5,000- to 10,000-MT exchange would have only minor effects.

(3) The climatic impact of sooty smoke from nuclear fires ignited by airbursts is expected to be more important than that of dust raised by surface bursts (when both effects occur). Smoke absorbs sunlight efficiently, whereas soil dust is generally nonabsorbing. Smoke particles are extremely small (typically $< 1\ \mu m$ in radius), which lengthens their atmospheric residence time. There is also a high probability that nuclear explosions over cities, forests, and grasslands will ignite widespread fires, even in attacks limited to missile silos and other strategic military targets.

(4) Smoke from urban fires may be more important than smoke from collateral forest fires for at least two reasons: (i) in a full-scale exchange, cities holding large stores of combustible materials are likely to be attacked directly; and (ii) intense fire storms could pump smoke into the stratosphere, where the residence time is a year or more.

(5) Nuclear dust can also contribute to the climatic impact of a nuclear exchange. The dust-climate effect is very sensitive to the conduct of the war; a smaller effect is expected when lower yield weapons are deployed and airbursts dominate surface land bursts. Multiburst phenomena might enhance the climatic effects of nuclear dust, but not enough data are available to assess this issue.

(6) Exposure to radioactive fallout may be more intense and widespread than predicted by empirical exposure models, which neglect intermediate fallout extending over many days and weeks, particularly when unprecedented quantities of fission debris are released abruptly into the troposphere by explosions with submegaton yields. Average NH midlatitude whole-body gamma-ray doses of up to 50 rads are possible in a 5,000-MT exchange; larger doses would accrue within the fallout plumes of radioactive debris extending hundreds of kilometers downwind of targets. These estimates neglect a proba-

bly significant internal radiation dose due to biologically active radionuclides.

(7) Synergisms between long-term nuclear war stresses—such as low light levels, subfreezing temperatures, exposure to intermediate time scale radioactive fallout, heavy pyrogenic air pollution, and UV-B flux enhancements—aggravated by the destruction of medical facilities, food stores, and civil services, could lead to many additional fatalities, and could place severe stresses on the global ecosystem. An assessment of the possible long-term biological consequences of the nuclear war effects quantified in this study is made by Ehrlich *et al.*[46]

Our estimates of the physical and chemical impacts of nuclear war are necessarily uncertain because we have used one-dimensional models, because the data base is incomplete, and because the problem is not amenable to experimental investigation. We are also unable to forecast the detailed nature of the changes in atmospheric dynamics and meteorology implied by our nuclear war scenarios, or the effect of such changes on the maintenance or dispersal of the initiating dust and smoke clouds. Nevertheless, the magnitudes of the first-order effects are so large, and the implications so serious, that we hope the scientific issues raised here will be vigorously and critically examined.

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19. Prediction of circulation anomalies and attendant changes in regional weather patterns requires an appropriately designed three-dimensional general circulation model with at least the following features: horizontal resolution of 10° or better, high vertical resolution through the troposphere and stratosphere, cloud and precipitation parameterizations that allow for excursions well outside present-day experience, ability to transport dust and smoke particles, an interactive radiative transport scheme to calculate dust and smoke effects on light fluxes and heating rates, allowance for changes in particle sizes with time and for wet and dry deposition, and possibly a treatment of the coupling between surface winds and ocean currents and temperatures. Even if such a model were available today, it would not be able to resolve questions of patchiness on horizontal scales of less than several hundred kilometers, of localized perturbations in boundary-layer dynamics, or of mesoscale dispersion and removal of dust and smoke clouds.
20. Advisors, *Ambio* **11**, 94 (1982).
21. R. T. Pretty, Ed., *Jane's Weapon Systems, 1982–1983* (Jane's, London, 1982).
22. *The Military Balance 1982–1983* (International Institute for Strategic Studies, London, 1982).
23. *World Armaments and Disarmament*, Stockholm International Peace Research Institute Yearbook 1982 (Taylor & Francis, London, 1982).
24. R. Forsberg, *Sci. Am.* **247**, 52 (November 1982).
25. The unprecedented difficulties involved in controlling a limited nuclear exchange are discussed by, for example, P. Bracken and M. Shubik [*Technol. Soc.* **4**, 155 (1982)] and by D. Ball [*Adelphi Paper 169* (International Institute for Strategic Studies, London, 1981)].
26. G. Kemp, *Adelphi Paper 106* (International Institute for Strategic Studies, London, 1974).
27. S. Glasstone and P. J. Dolan, Eds., *The Effects of Nuclear Weapons* (Department of Defense, Washington, D.C., 1977).
28. The areas cited are subject to peak overpressures $\geq$ 10 to 20 cal/cm^2.
29. A 1-MT surface explosion ejects $\sim 5 \times 10^6$ tons of debris, forming a large crater.[27] Typical soils consist of $\simeq$ 5 to 25 percent by weight of grains $\leq 1\ \mu m$ in radius [G. A. D'Almeida and L. Schutz, *J. Climate Appl. Meteorol.* **22**, 233 (1983); G. Rawson, private communication]. However, the extent of disaggregation of the soil into parent grain sizes is probably $\leq$ 10 percent [R. G. Pinnick, G. Fernandez, B. D. Hinds, *Appl. Opt.* **22**, 95 (1983)] and would depend in part on soil moisture and compaction.
30. A 1-MT surface explosion vaporizes $\simeq 2 \times 10^4$ to 4×10^4 tons of soil,[27] which is ingested by the fireball. Some silicates and other refractory materials later renucleate into fine glassy spheres [M. W. Nathans, R. Thews, I. J. Russell, *Adv. Chem. Ser.* **93**, 360 (1970)].
31. A 1-MT surface explosion raises significant quantities of dust over an area

of ≥ 100 km^2 by "popcorning," due to thermal radiation, and by saltation, due to pressure winds and turbulence." Much of the dust is sucked up by the afterwinds behind the rising fireball. Size sorting should favor greatest lifting for the finest particles. The quantity of dust lofted would be sensitive to soil type, moisture, compaction, vegetation cover, and terrain. Probably $> 1 \times 10^5$ tons of dust per megaton can be incorporated into the stabilized clouds in this manner.

32. R. G. Gutmacher, G. H. Higgins, H. A. Tewes, *Lawrence Livermore Lab. Rep. UCRL-14397* (1983); J. Carpenter, private communication.
33. M. W. Nathans, R. Thews, I. J. Russell (in Ref. 30). These data suggest number size distributions that are log-normal at small sizes ($\leq$ 3 μm) and power law ($r^{-\alpha}$) at larger sizes. Considering data from a number of nuclear tests, we adopted an average log-normal mode radius of 0.25 μm, $\sigma = 2.0$, and an exponent, $\alpha = 4$." If all particles in the stabilized clouds have radii in the range 0.01 to 1000 μm, the adopted size distribution has ≃ 8 percent of the total mass in particles ≤ 1 μm in radius; this fraction of the stabilized cloud mass represents ≤ 0.5 percent of the total ejecta and sweep-up mass of a surface explosion and amounts to ≃ 25 tons per kiloton of yield.
34. Atmospheric dust from volcanic explosions differs in several important respects from that produced by nuclear explosions. A volcanic eruption represents a localized dust source, while a nuclear war would involve thousands of widely distributed sources. The dust mass concentration in stabilized nuclear explosion clouds is low (≤ 1 g/m^3), while volcanic eruption columns are so dense they generally collapse under their own weight [G. P. L. Walker, *J. Volcanol. Geotherm. Res.* **11**, 81 (1981)]. In the dense volcanic clouds particle agglomeration, particularly under the influence of electrical charge, can lead to accelerated removal by sedimentation [S. N. Carey and H. Sigurdsson, *J. Geophys. Res.* **87**, 7061 (1982); S. Brazier *et al.*, *Nature (London)* **301** 115 (1983)]. The size distribution of volcanic ash is also fundamentally different from that of nuclear dust [W. I. Rose *et al.*, *Am. J. Sci.* **280**, 671 (1980)], because the origins of the particles are so different. The injection efficiency of nuclear dust into the stratosphere by megaton-yield explosions is close to unity, while the injection efficiency of fine volcanic dust appears to be very low." For these reasons and others, the observed climatic effects of major historical volcanic eruptions cannot be used, as in Ref. 2, to calibrate the potential climatic effect of nuclear dust merely by scaling energy or soil volume. However, in cases where the total amount of submicrometer volcanic material that remained in the stratosphere could be determined, climate models have been applied and tested [J. B. Pollack *et al.*, *J. Geophys. Res.* **81**, 1071 (1976)]. We used such a model in this study to predict the effects of specific nuclear dust injections.
35. E. Ishikawa and D. L. Swain, Translators, *Hiroshima and Nagasaki: The Physical, Medical and Social Effects of the Atomic Bombings* (Basic Books, New York, 1981).
36. At Hiroshima, a weapon of roughly 13 KT created a fire over ≃ 13 km^2. At Nagasaki, where irregular terrain inhibited widespread fire ignition, a weapon of roughly 22 KT caused a fire over ≃ 7 km^2. These two cases suggest that low-yield (≤ 1-MT) nuclear explosions can readily ignite fires over an area of ≃ 0.3 to 1.0 km^2/KT—roughly the area contained within the ≃ 10 cal/cm^2 and the ≃ 2 psi overpressure contours."
37. A. Broido, *Bull. At. Sci.* **16**, 409 (1960).
38. C. F. Miller, "Preliminary evaluation of fire hazards from nuclear detonations," *SRI (Stanford Res. Inst.) Memo. Rep. Project IMU-4021-302* (1962).
39. R. U. Ayers, *Environmental Effects of Nuclear Weapons* (HI-518-RR, Hudson Institute, New York, 1965), vol. 1.
40. S. B. Martin, "The role of fire in nuclear warfare," *United Research Services Rep. URS-764 (DNA 2692F)* (1974).

41. *DCPA Attack Environment Manual* (Department of Defense, Washington, D.C., 1973), chapter 3.
42. *FEMA Attack Environment Manual* (CPG 2-1A3, Federal Emergency Management Agency, Washington, D.C., 1982), chapter 3.
43. H. L. Brode, "Large-scale urban fires," *Pacific Sierra Res. Corp. Note 348* (1980).
44. D. A. Larson and R. D. Small, "Analysis of the large urban fire environment," *Pacific Sierra Res. Corp. Rep. 1210* (1982).
45. Urban and suburban areas of cities with populations exceeding 100,000 (about 2300 worldwide) are surveyed in Ref. 15. Also discussed are global reserves of flammable substances, which are shown to be roughly consistent with known rates of production and accumulation of combustible materials. P. J. Crutzen and I. E. Galbally (in preparation) reach similar conclusions about global stockpiles of combustibles.
46. Smoke emission data for forest fires are reviewed by D. V. Sandberg, J. M. Pierovich, D. G. Fox, and E. W. Ross ["Effects of fire on air," *U.S. Forest Serv. Tech. Rep. WO-9* (1979)]. Largest emission factors occur in intense large-scale fires where smoldering and flaming exist simultaneously, and the oxygen supply may be limited over part of the burning zone. Smoke emissions from synthetic organic compounds would generally be larger than those from forest fuels [C. P. Bankston, B. T. Zinn, R. F. Browner, E. A. Powell, *Combust. Flame* 41, 273 (1981)].
47. Sooty smoke is a complex mixture of oils, tars, and graphitic (or elemental) carbon. Measured benzene-soluble mass fractions of wildfire smokes fall in the range $\simeq$ 40 to 75 percent (D. V. Sandberg *et al.* in Ref. 46). Most of the residue is likely to be brown to black (the color of smoke ranges from white, when large amounts of water vapor are present, to yellow or brown, when oils predominate, to gray or black, when elemental carbon is a major component).
48. A. Tewarson, in *Flame Retardant Polymeric Material*, M. Lewin, S. M. Atlas, E. M. Pierce, Eds. (Plenum, New York, 1982), vol. 3, pp. 97–153. In small laboratory burns of a variety of synthetic organic compounds, emissions of "solid" materials (which remained on collection filters after baking at 100°C for 24 hours) ranged from $\simeq$ 1 to 15 percent by weight of the carbon consumed; of low-volatility liquids, $\simeq$ 2 to 35 percent; and of high-volatility liquids, $\simeq$ 1 to 40 percent. Optical extinction of the smoke generated by a large number of samples varied from $\simeq$ 0.1 to 1.5 m^2 per gram of fuel burned.
49. In wildfires, the particle number mode radius is typically about 0.05 μm (D. V. Sandberg *et al.*, in Ref. 46). For burning synthetics the number mode radius can be substantially greater, but a reasonable average value is 0.1 μm (C. P. Bankston *et al.*, in Ref. 46). Often, larger debris particles and firebrands are swept up by powerful fire winds, but they have short atmospheric residence times and are not included in the present estimates (C. K. McMahon and P. W. Ryan, paper presented at the 69th Annual Meeting, Air Pollution Control Association, Portland, Ore., 27 June to 1 July 1976). Nevertheless, because winds exceeding 100 km/hour may be generated in large-scale fires, significant quantities of fine noncombustible surface dust and explosion debris (such as pulverized plaster) might be lifted in addition to the smoke particles.
50. This assumes an average graphitic carbon mass fraction of about 30 to 50 percent, for a pure carbon imaginary refractive index of 0.6 to 1.0 [J. T. Twitty and J. A. Weinman, *J. Appl. Meteorol.* 10, 725 (1971); S. Chippett and W. A. Gray, *Combust. Flame* 31, 149 (1978)]. The real part of the refractive index of pure carbon is 1.75, and for many oils is 1.5 to 1.6. Smoke particles were assigned an average density of 1 g/cm^3 (C. K. McMahon, paper presented at the 76th Annual Meeting, Air Pollution Control Association, Atlanta, Ga., 19 to 24 June 1983). Solid graphite has a density $\simeq$ 2.5 g/cm^3, and most oils, $\lesssim$ 1 g/cm^3.
51. A number of targets with military, economic, or political significance can also be identified in tropical northern latitudes and in the SH.[20]

52. Attenuation of direct sunlight by dust and smoke particles obeys the law $I/I_0 = \exp(-\tau/\mu_0)$, where τ is the total extinction optical depth due to photon scattering and absorption by the particles and μ_0 is the cosine of the solar zenith angle. The optical depth depends on the wavelength of the light and the size distribution and composition of the particles, and is generally calculated from Mie theory (assuming equivalent spherical particles). The total light intensity at the ground consists of a direct component and a diffuse, or scattered, component, the latter usually calculated with a radiative transfer model. The extinction optical depth can be written as $\tau = XML$, where X is the specific cross section (m²/g particulate), M the suspended particle mass concentration (g/m³), and L the path length (m). It is the sum of a scattering and an absorption optical depth ($\tau = \tau_s + \tau_a$). Fine dust and smoke particles have scattering coefficients $X_s \approx 3$ to 5 m²/g at visible wavelengths. However, the absorption coefficients X_a are very sensitive to the imaginary part of the index of refraction. For typical soil particles, $X_a \leq 0.1$ m²/g. For smokes, X_a can vary from ~ 0.1 to 10 m²/g, roughly in proportion to the volume fraction of graphite in the particles. Occasionally, specific extinction coefficients for smoke are given relative to the mass of fuel burned; then X implicitly includes a multiplicative emission factor (grams of smoke generated per gram of fuel burned).
53. R. P. Turco, O. B. Toon, R. C. Whitten, P. Hamill, *Eos* 63, 901 (1982).
54. J. A. Ogren, in *Particulate Carbon: Atmospheric Life Cycle*, G. T. Wolff and R. L. Klimisch, Eds. (Plenum, New York: 1982), pp. 379–391.
55. To estimate the wildfire area, we assume that 25 percent of the total nonurban yield, or 1000 MT, ignites fires over an area of 500 km²/MT—approximately the zone irradiated by 10 cal/cm²—and that the fires do not spread outside this zone.” R. E. Huschke [*Rand Corp. Rep. RM-5073-TAB* (1966)] analyzed the simultaneous flammability of wildland fuels in the United States, and determined that about 50 percent of all fuels are at least moderately flammable throughout the summer months. Because $\simeq$ 50 percent of the land areas of the countries likely to be involved in a nuclear exchange are covered by forest and brush, which are flammable about 50 percent of the time, the 1000-MT ignition yield follows statistically.
56. Most of the background smoke is injected into the lowest 1 to 2 km of the atmosphere, where it has a short lifetime, and consists on the average of $\leq$ 10 percent graphitic carbon [R. P. Turco, O. B. Toon, R. C. Whitten, J. B. Pollack, P. Hamill, in *Precipitation Scavenging, Dry Deposition and Resuspension*, H. R. Pruppacher, R. G. Semonin, W. G. N. Slinn, Eds. (Elsevier, New York, 1983), p. 1337]. Thus, the average optical depth of ambient atmospheric soot is only $\leq$ 1 percent of the initial optical depth of the baseline nuclear war smoke pall.
57. H. E. Landsberg and J. M. Albert, *Weatherwise* 27, 63 (1974).
58. H. Stommel and E. Stommel, *Sci. Am.* 240, 176 (June 1979).
59. O. B. Toon and J. B. Pollack, *Nat. Hist.* 86, 8 (January 1977).
60. H. H. Lamb, *Climate Present, Past and Future* (Methuen, London, 1977), vols. 1 and 2.
61. Notwithstanding possible alterations in the surface albedo due to the fires and deposition of soot. [15, 80]
62. S. G. H. Philander, *Nature (London)* 302, 295 (1983); B. C. Weare, *Science* 221, 947 (1983).
63. D. H. Milne and C. P. McKay, *Geol. Soc. Am. Spec. Pap. 190* (1982), p. 297.
64. O. B. Toon, *Eos* 63, 901 (1982).
65. The stratosphere is normally defined as the region of constant or increasing temperature with increasing height lying just above the troposphere. The residence time of fine particles in the stratosphere is considerably longer than in the upper troposphere because of the greater stability of the stratospheric air layers and the absence of precipitation in the stratosphere. With large smoke injections, however, the

ambient temperature profile would be substantially distorted (for instance, see Fig. 3) and a "stratosphere" might form in the vicinity of the smoke cloud, increasing its residence time at all altitudes.[13] Thus the duration of sunlight attenuation and temperature perturbations in Figs. 1 to 6 may be considerably underestimated.

66. Transport of soot from the boundary layer into the overlying free troposphere can occur by diurnal expansion and contraction of the boundary layer, by large-scale advection, and by strong localized convection.
67. F Barnaby and J. Rotblat, *Ambio* 11, 84 (1982).
68. The term "intermediate" fallout distinguishes the radioactivity deposited between several days and ~ 1 month after an exchange from "prompt" fallout (≤ 1 day) and "late" fallout (months to years). Intermediate fallout is expected to be at least hemispheric in scale and can still deliver a significant chronic whole-body gamma-ray dose. It may also contribute a substantial internal dose, for example, from ^{131}I. The intermediate time scale gamma-ray dose represents, in one sense, the minimum average exposure far from targets and plumes of prompt fallout. However, the geographic distribution of intermediate fallout would still be highly variable, and estimates of the average dose made with a one-dimensional model are greatly idealized. The present calculations were calibrated against the observed prompt fallout of nuclear test explosions.[13]
69. There is also reason to believe that the fission yield fraction of nuclear devices may be increasing as warhead yields decrease and uranium processing technology improves. If the fission fraction were unity, our dose estimates would have to be doubled. We also neglect additional potential sources of radioactive fallout from salted "dirty" weapons and explosions over nuclear reactors and fuel reprocessing plants.
70. J. Knox (*Lawrence Livermore Lab. Rep. UCRL-89907,* in press) reports fallout calculations which explicitly account for horizontal spreading and transport of nuclear debris clouds. For a 5300-MT strategic exchange, Knox computes average whole-body gamma-ray doses of 20 rads from 40° to 60°N, with smaller average doses elsewhere. Hot spots of up to 200 rads over areas of ~ 10^6 km^2 are also predicted for intermediate time scale fallout. These calculations are consistent with our estimates.
71. H. Lee and W. E. Strope [*Stanford Res. Inst. Rep. EGU 2981* (1974)] studied U.S. exposure to transoceanic fallout generated by several assumed Sino-Soviet nuclear exchanges. Taking into account weathering of fallout debris, protection by shelters, and a 5-day delay before initial exposure, potential whole-body gamma-ray doses ≤ 10 rads and internal doses ≥ 10 to 100 rads, mainly to the thyroid and intestines, were estimated.
72. These estimates assume normal rates and patterns of precipitation, which control the intermediate time scale radioactive fallout. In severely perturbed cases, however, it may happen that the initial dispersal of the airborne radioactivity is accelerated by heating, but that intermediate time scale deposition is suppressed by lack of precipitation over land.
73. H. Johnston, G. Whitten, J. Birks, *J. Geophys. Res.* 78, 6107 (1973); H. S. Johnston, *ibid.* 82, 3119 (1977).
74. S. A. W. Gerstl, A. Zardecki, H. L. Wiser, *Nature (London)* 294, 352 (1981).
75. M. P. Esposito, T. O. Tiernan, F. E. Dryden, *U.S. EPA Rep. EPA-600/280-197* (1980).
76. J. Josephson, *Environ. Sci. Technol.* 17, 124A (1983). In burning of PCB's, for example, release of toxic polycyclic chlorinated organic compounds can amount to 0.1 percent by weight. In the United States more than 300,000 tons of PCB's are currently in use in electrical systems [S. Miller, *Environ. Sci. Technol.* 17, 11A (1983)].

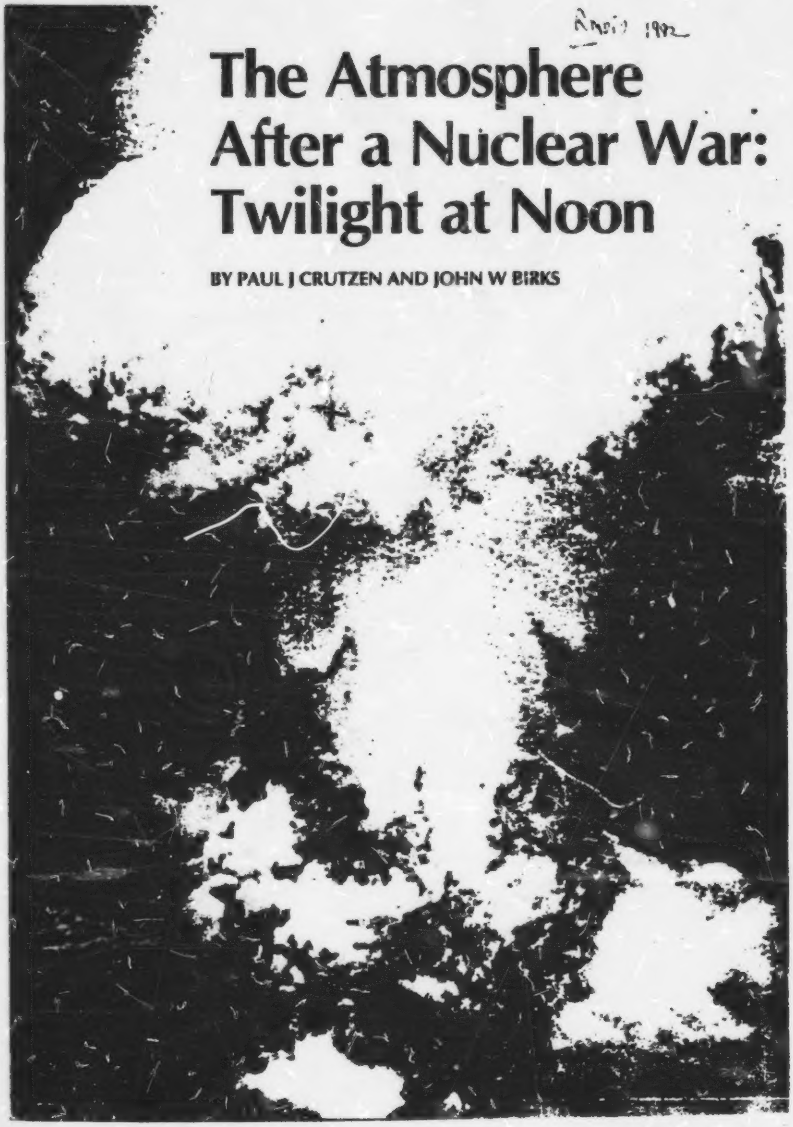
77. C.-S. Chen and H. D. Orville [*J. Appl. Meteorol.* **16**, 401 (1977)] model the effects of fine graphitic dust on cumulus-scale convection. They show that strong convective motions can be established in still air within 10 minutes after the injection of a kilometer-sized cloud of submicrometer particles of carbon black, at mixing ratios $\leq$ 50 ppb by mass. Addition of excess humidity in their model to induce rainfall results in still stronger convection; the carbon dust is raised higher and spread farther horizontally, while $\leq$ 20 percent is scavenged by the precipitation. W. M. Gray, W. M. Frank, M. L. Corrin, and C. A. Stokes [*J. Appl. Meteorol.* **15**, 355 (1976)] discuss possible mesoscale ($\geq$ 100 km) weather modifications due to large carbon dust injections.
78. C. Covey, S. Schneider, and S. Thompson (*Nature*, Vol. 308, pp. 21–25, March 1984) report GCM simulations which include soot burdens similar to those in our baseline case. They find major perturbations in the global circulation within a week of injection, with strong indications that some of the nuclear debris at northern midlatitudes would be transported upward and toward the equator.
79. R. C. Eagan, P. V. Hobbs, L. F. Radke, *J. Appl. Meteorol.* **13**, 553 (1974).
80. C. Sagan, O. B. Toon, and J. B. Pollack [*Science* **206**, 1363 (1979)] discuss the impact of anthropogenic albedo changes on global climate. Nuclear war may cause albedo changes by burning large areas of forest and grassland; by generating massive quantities of soot which can settle out on plants, snowfields, and ocean surface waters; and by altering the pattern and extent of ambient water clouds. The nuclear fires in the baseline case consume an area $\simeq 7.5 \times 10^5$ km^2, or only $\simeq$ 0.5 percent of the global landmass; it is doubtful that an albedo variation over such a limited area is significant. All the soot in the baseline nuclear war case, if spread uniformly over the earth, would amount to a layer $\sim$ 0.5 μm thick. Even if the soot settled out uniformly on all surfaces, the first rainfall would wash it into soils and watersheds. The question of the effect of soot on snow and ice fields is under debate (J. Birks, private communication). In general, soot or sand accelerates the melting of snow and ice. Soot that settles in the oceans would be rapidly removed by nonselective filterfeeding plankton, if these survived the initial darkness and ionizing radiation.
81. In the present calculations, chemical changes in stratospheric O_3 and NO_x concentrations cause a small average temperature perturbation compared to that caused by nuclear dust and smoke; it seems unlikely that chemically induced climatic disturbances would be a major factor in a nuclear war. Tropospheric ozone concentrations, if tripled,' would lead to a small greenhouse warming of the surface [W. C. Wang, Y. L. Yung, A. A. Lacis, T. Mo, J. E. Hansen, *Science* **194**, 685 (1976)]. This might result in more rapid surface temperature recovery. However, the tropospheric O_3 increase is transient ($\sim$ 3 months in duration) and probably secondary in importance to the contemporaneous smoke and dust perturbations.
82. R. M. Haberle, C. B. Leovy, J. B. Pollack, *Icarus* **50**, 322 (1983).
83. During the martian dust storm of 1971–1972, the IRIS experiment on Mariner 9 observed that suspended particles heated the atmosphere and produced a vertical temperature gradient that was substantially subadiabatic [R. B. Hanel *et al.*, *Icarus* **17**, 423 (1972); J. B. Pollack *et al.*, *J. Geophys. Res.* **84**, 2929 (1979)].
84. V. V. Alexandrov, private communication; S. H. Schneider, private communication.
85. G. E. Thomas, B. M. Jakosky, R. A. West, R. W. Sanders, *Geophys. Res. Lett.* **10**, 997 (1983); J. B. Pollack *et al.*, *ibid.*, p. 989; B. M. Jakosky, private communication.
86. P. Ehrlich *et al.*, *Science* **222**, 1293 (1983).
87. H. M. Foley and M. A. Ruderman, *J. Geophys. Res.* **78**, 4441 (1973).
88. We gratefully acknowledge helpful discussions with J. Berry, H. A. Bethe, C.

Billings, J. Birks, H. Brode, R. Cicerone, L. Colin, P. Crutzen, R. Decker, P. J. Dolan, P. Dyal, F. J. Dyson, P. Ehrlich, B. T. Feld, R. L. Garwin, F. Gilmore, L. Grinspoon, M. Grover, J. Knox, A. Kuhl, C. Leovy, M. MacCracken, J. Mahlman, J. Marcum, P. Morrison, E. Patterson, R. Perret, G. Rawson, J. Rotblat, E. E. Salpeter, S. Soter, R. Speed, E. Teller, and R. Whitten on a variety of subjects related to this work. S. H. Schneider, C. Covey, and S. Thompson of the National Center for Atmospheric Research generously shared with us preliminary GCM calculations of the global weather effects implied by our smoke emissions. We also thank the almost 100 participants of a 5-day symposium held in Cambridge, Mass., 22 to 26 April, for reviewing our results; that symposium was organized by the Conference on the Longterm Worldwide Biological Consequences of Nuclear War under a grant from the W. Alton Jones Foundation. Special thanks go to Janet M. Tollas for compiling information on world urbanization, to May Liu for assistance with computer programming, and to Mary Maki for diligence in preparing the manuscript.

Ambio 1982

The Atmosphere After a Nuclear War: Twilight at Noon

BY PAUL J CRUTZEN AND JOHN W BIRKS



As a result of a nuclear war vast areas of forests will go up in smoke—corresponding at least to the combined land mass of Denmark, Norway and Sweden. In addition to the tremendous fires that will burn for weeks in cities and industrial centers, fires will also rage across croplands and it is likely that at least 1.5 billion tons of stored fossil fuels (mostly oil and gas) will be destroyed. The fires will produce a thick smoke layer that will drastically reduce the amount of sunlight reaching the earth's surface. This darkness would persist for many weeks, rendering any agricultural activity in the Northern Hemisphere virtually impossible if the war takes place during the growing season.

The immediate effects of a global nuclear war are so severe that any additional long-term effects might at first thought be regarded as insignificant in comparison. However, our investigation into the state of the atmosphere following a nuclear exchange suggests that other severely damaging effects to human life and the delicate ecosystems to which we belong will occur during the following weeks and months. Many of these effects have not been evaluated before.

Previous investigations of the atmospheric effects following a nuclear war have been concentrated primarily on the expected large depletions of ozone in the stratosphere (1,2). Reduction of the stratospheric ozone shield allows increased levels of harmful ultraviolet (uv) radiation to penetrate to the surface of the earth. Such ozone depletion results from the injection of oxides of nitrogen (NO_x) by large nuclear weapons having yields greater than one megaton. Should the nations having nuclear arsenals choose to use their large warheads in a nuclear war, then the earth's protective ozone layer would be much depleted, and the consequent adverse effects associated with the increased flux of ultraviolet radiation would occur. Our conclusions for such a scenario concur with those found in the 1975 report of the US National Academy of Sciences (1).

As assumed in Ambio's reference scenario, it is now believed that the most likely nuclear war is one in which few weapons having yields greater than 1 Mt are used, with preference given to the detonation of large numbers of smaller yield weapons. For such a nuclear war, very little NO_x would be injected above 15 km into the stratosphere by the nuclear bursts, and thus depletion of the ozone layer would not occur as a direct result of the explosions. Nonetheless, other profound effects on the atmosphere can be expected.

In discussing the state of the atmosphere following a nuclear exchange, we point especially to the effects of the many fires that would be ignited by the thousands of nuclear explosions in cities, forests, agricultural fields, and oil and gas fields. As a result of these fires, the loading of the atmosphere with strongly light absorbing particles in the submicron size range (1 micron = 10^{-6} m) would increase so much that at noon solar radiation at the ground would be reduced by at least a factor of two and possibly a factor of greater than one hundred. In addition, fires inject large quantities of oxides of nitrogen and reactive hydrocarbons, the ingredients of photochemical smog. This creates the potential for photochemical smog throughout much of the Northern Hemisphere which may persist for several months after the particulate matter has been deposited on the ground. Such effects have been largely overlooked or not carefully examined in previous considerations of this problem. They are, therefore, considered in some detail in this study.

NUCLEAR WAR SCENARIOS

The explosion of nuclear weapons produces oxides of nitrogen by heating air to temperatures well above 2000 K. When the major constituents of the air—nitrogen and oxygen—are heated to high temperature, nitric oxide (NO) is formed. The equilibrium between N_2, O_2 and NO is rapidly approached at the temperatures characteristic of the nuclear explosions:

$$N_2 + O_2 \leftrightarrow 2\,NO$$

As the temperature of the heated air falls, the reactions which maintain equilibrium become slow and NO cannot revert to the innocuous oxygen and nitrogen. Consequently, nuclear explosions produce NO in much the same way as it is formed as a pollutant in automobile and aircraft engines. A review of the mechanisms forming NO in nuclear explosions is provided in Appendix I. The oxides of nitrogen are important trace atmospheric constituents and play a very important role in atmospheric photochemistry. They are key constituents in the formation of photochemical smog in the troposphere, and the catalytic reaction cycle leading to ozone destruction is the principal means by which ozone concentrations are regulated in the stratosphere. In Appendix I it is estimated that there are 1×10^{32} molecules of NO formed for each megaton of explosion yield. As will be discussed later, large amounts of nitric oxide would also be formed by the many fires that would be started during a nuclear war.

With regard to direct NO_x formation in nuclear explosions, we consider two nuclear war scenarios. Scenario I is Ambio's reference scenario (3). In this scenario

Table 1. Distribution of NO_x produced by nuclear explosions for Scenario I ($\times 10^{32}$ molecules).

Alt. (km)	60°S–30°S	30°S–EQ	EQ–20°N	20°N–40°N	40°N–60°N	60°N–NP	Sum
30	–	–	–	0.7	–	–	0.7
29	–	–	–	0.7	1	–	1.7
28	–	–	–	2.3	1	–	3.3
27	–	–	–	2.3	3	–	5.3
26	–	–	–	2.3	3	–	5.3
25	–	–	–	2.3	3	–	5.3
24	–	–	–	3.7	3	–	6.7
23	–	–	–	3.7	5	–	8.7
22	–	–	–	3.7	5	–	8.7
21	–	–	–	3.7	5	–	8.7
20	–	–	–	2.1	5	–	7.1
19	–	–	–	2.1	2.8	–	4.9
18	–	0.3	1.1	0.1	2.8	–	4.3
17	–	1.1	3.5	10.4	0.2	–	15.2
16	0.7	3.5	10.8	30.7	24.5	–	70.2
15	2.3	8.9	27.5	30.7	72.9	–	142.3
14	2.3	8.9	27.5	116.8	72.9	1.1	229.5
13	3.7	13.0	39.7	247.7	121.5	3.5	429.1
12	8.5	12.1	36.7	225.1	276.6	3.5	562.5
11	16.6	6.6	20.4	329.4	533.5	11.9	918.4
10	14.6	0.5	1.5	327.3	470.2	26.4	840.5
9	24.4	–	–	183.2	775.8	25.0	1 008.4
8	24.4	–	–	13.2	775.8	36.7	850.1
7	13.6	–	–	–	434.4	36.5	484.5
6	1.0	–	–	–	21.0	20.4	42.4
5	–	–	–	–	–	1.5	1.5
Sum	112.1	54.9	168.7	1 544.2	3 618.9	166.5	5 665.3

bombs having a total yield of 5750 Mt are detonated. The latitudinal and vertical distributions of the 5.7×10^{35} molecules of nitric oxide produced in these explosions are determined by the weapon sizes and targets projected for this scenario. Since most of the weapons have yields less than 1 Mt, most of the NO_x is deposited in the troposphere, and the effect on the chemistry of the stratosphere is much less than if the bomb debris were deposited mainly in the stratosphere. The assumed NO input pattern for the Scenario I war is provided in Table 1.

The Scenario II war is similar to those used in previous studies by investigators using one-dimensional models and is included here mostly for historical reasons. This scenario considers a total yield of 10 000 Mt uniformly distributed between 20° and 60° in the Northern Hemisphere. The vertical distribution of NO is calculated assuming equal yields of 1-Mt and 10-Mt weapons, *ie* 5000 1-Mt weapons and 500 10-Mt weapons are detonated. For this scenario, equal quantities of NO_x are injected above and below 18 km, as seen in Table 2. Thus, the tropospheric effects for the Scenario II war are similar to those for the Scenario I war. However, the Scenario II war also results in an additional large perturbation of the stratospheric ozone layer.

FIRES

From an atmospheric point of view, the most serious effects of a nuclear war would most likely result from the many fires which would start in the war and could not be extinguished because of nuclear contaminations and loss of water lines, fire equipment and expert personnel. The devastating effects of such fires in urban areas were indicated by Lewis (4). Here we show that the atmospheric effects would be especially dramatic. Several types of fires may rage. Besides the fires in urban and industrial centers, vast forest fires would start, extensive grasslands and agricultural land would burn, and it is likely that many natural gas and oil wells would be ruptured as a result of the nuclear explosions, releasing huge quantities of oil and natural gas, much of which would catch fire. To give an estimate of the possible effects, we will consider as a working hypothesis that 10^6 km² of forests will burn (this corresponds roughly to the combined area of Denmark, Norway and Sweden) and that breaks in gas and oil production wells will release gaseous effluents from the earth corresponding to the current rate of worldwide usage. In our opinion these are underestimates of the real extent of fires that would occur in a major nuclear war (see also Box 1).

Gaseous and Particulate Emissions from Forest Fires

In the US and especially in Canada and the USSR, vast forests are found close to important urban strategic centers, so that it may be expected that many wildfires would start burning during and after the nuclear exchange. Although it is hard to estimate how much forest area might burn, a total of 10^6 km², spread around in the Northern Hemisphere, is probably an underestimate, as it is only about 20 times larger than what is now annually consumed by wildfires (5). This amounts to 4 percent of the temperate and boreal forest lands, and is not larger than that of the urban areas combined (6). Furthermore, Ward *et al* (7) have pointed out that effective fire control and prevention programs have reduced the loss of forests in the US (exclusive of Alaska) from 1.8×10^5 km² in the early 1930's to less than 1.6×10^4 km² by the mid 1970's. The US Forest Service is quoted as estimating that a nuclear attack on the US of ~1500 Mt would burn a land area of $0.4–6 \times 10^5$ km² in the US (8). All this information indicates that our assumption of 10^6 km² of forest area that could be consumed by fire is not an overestimate.

An area of 10^6 km² of forest contains on the average about 2.2×10^{16} g dry matter or about 10^{16} g of carbon phytomass (6) and about 10^{14} g of fixed nitrogen, not counting the material which is contained in soil organic matter. Typically, during forest wildfires about 25 percent of the available phytomass is burned (5), so that 2.5×10^{15} g of carbon would be released to the atmosphere. During wildfires about 75 kg of particulate matter is produced per ton of forest material burned or 450 kg of carbon (7), so that 4×10^{14} g of particulate matter is injected into the atmosphere by the forest fires. Independently, we can use the information by Ward *et al* (7) to estimate the global biomass and suspended particulate matter expected to be produced by wildfires which would be started by the nuclear war. According to these authors the forest area now burned annually in the US, excluding Alaska, is about 1.8×10^4 km², which delivers 3.5×10^{12} g particulate matter to the atmosphere. Accordingly, a total area of 10^6 km² would inject 2×10^{14} g particulate matter into the atmosphere, which should come from 3×10^{15} g of burned forest material, or 1.3×10^{15} g C. This is a factor of two less than the earlier derived estimate, so we will use a range of $1.3–2.5 \times 10^{15}$ g of carbon as the global atmospheric gaseous release and $2–4 \times 10^{14}$ g as particulate matter.

In forest fires most of the carbon is released as CO_2 to the atmosphere. The forest fire contribution to the atmospheric CO_2 content, which totals 7×10^{17} g of carbon, is rather insignificant. The repercussions of the forest fires are, however, much more important for the contribution of other gases to the atmosphere, *eg* carbon monoxide (CO). With a relative release rate ratio $CO:CO_2$ of about 15 percent (9), the production of CO would amount to $2–4 \times 10^{14}$ g C, which is roughly equal to or two times larger than the present atmospheric CO content (10). Within a short period of time, average concentrations of CO at midlatitudes in the Northern Hemisphere would increase by up to a factor of four, and much larger CO increases may be expected on the continents, especially

Table 2. Distribution of NO_x produced by nuclear explosions for Scenario II (× 10^{32} molecules).

Alt. (km)	20° N–40° N	40° N–60° N	Sum
31	62	62	124
30	62	62	124
29	188	188	376
28	188	188	376
27	188	188	376
26	188	188	376
25	312	312	624
24	312	312	624
23	312	312	624
22	312	312	624
21	175	175	350
20	175	175	350
19	80	80	160
18	54	54	108
17	80	80	160
16	125	125	250
15	375	375	750
14	375	375	750
13	625	625	1 250
12	625	625	1 250
11	350	350	700
10	25	25	50
Sum	5 000	5 000	10 000

BOX 1.

The attenuations of sunlight at great distances from forest fires have been documented for many years. Phenomena such as "dark days", "dry fog", "Indian summer" and "colored rain" are now attributed to smoke produced by fires in forests, prairies and peat bogs. The great forest fires during October 13–17, 1918 in Minnesota and adjacent sections of Wisconsin produced smoke that had strong optical effects and could even be smelled as far away as the eastern US coast. A report from Cincinnati, Ohio is particularly descriptive (H Lyman, Reference 17): "At 3 PM the smoke and haze became denser, but the sun's light and its disk could be seen until 3:35 PM, at which time the sun was entirely obscured. Objects at this time could not be seen at a distance of 300 feet." More than 100 forest fires in northwestern Alberta and northeastern British Columbia resulted in the "Great Smoke Pall" of September 24–30, 1950 with press reports carrying accounts of smoke being observed as far away as England, France, Portugal, Denmark and Sweden (H Wexler, Reference 17). Most of Canada and the eastern one-third of the continental US were particularly affected. In the eastern US the smoke was confined to the altitude range of about 2.5–4.5 km, so that there was no reduced visibility at the ground. However, the sun was so obscured that it was visible to the naked eye without discomfort and had what was typically described as a violet or lavender color. Measurements in Washington, DC indicated that the solar intensity was reduced by a factor of two on September 25–26 in the absence of clouds.

in regions downwind (generally east of the fires). Accompanying those emissions there will also be significant inputs of tens of Teragrams (1 Teragram = 1 Tg = 10^{12} g) of reactive hydrocarbons to the atmosphere, mostly ethylene (C_2H_4) and propylene (C_3H_6), which are important ingredients in urban, photochemical smog formation. More important, phytomass consists roughly of about 1 percent fixed nitrogen, which is mainly contained in the smaller-sized material such as leaves, bark, twigs and small branches, which are preferentially burned during fires. As a rough estimate, because of the forest fires we may expect an input of 15–30 Tg of nitrogen into the atmosphere (7). Such an emission of NO would be larger than the production in the nuclear fireballs and comparable to the entire annual input of NO_x by industrial processes. Considering the critical role of NO in the production of tropospheric ozone, it is conceivable that a large accumulation of ozone in the troposphere, leading to global photochemical smog conditions, may take place. An increase of ozone due to photochemical processes in forest fire plumes has indeed been observed by several investigators (11, 12).

Particulate Matter from Forest Fires and Screening of Sunlight

The total production of 2–4×10^{14} g of particulate matter from the burning of 10^6 km^2 of forests is comparable on a volume basis to the total global production of particulate matter with diameter less than 3 microns (μm) over an entire year (or 200–400 million tons, 13). The physical and chemical nature of this material has been reviewed (14).

The bulk of the mass (>90 percent) of the particulate matter from forest fires consists of particles with diameters of less than 1 μm and a maximum particle number density at a diameter of 0.1 μm. The material has a very high organic matter content (40–75 percent) and much of it is formed from gaseous organic precursors. Its composition is on the average: 55 percent tar, 25 percent soot and 20 percent ash. These particles strongly absorb sunlight and infrared radiation. The light extinction coefficient, b_s (m), is related to the smoke density, d (g/m^3), by the relationship $b_s = ad$, where a is approximately 4–9 m^2/g (14, 15). With most smoke particles in the submicron size range, their average residence time in the atmosphere is about 5–10 days (13). If we assume that the forest fires will last for two months (16), a spread of 2–4×10^{14} g of aerosol over half of the Northern Hemisphere will cause an average particle loading such that the integrated vertical column of particles is equal to 0.1–0.5 g/m^2. As a result, the average sunlight penetration to the ground will be reduced by a factor between 2 and 150 at noontime in the summer. This would imply that much of the Northern Hemisphere would be darkened in the daytime for an extended period of time following the nuclear exchange. The large-scale atmospheric effects of massive forest fires have been documented in a number of papers (16, 17). Big forest fires in arctic regions are commonly accompanied by huge fires in peat bogs, which may burn over two meters in depth without any possibility of being extinguished (16).* The production of aerosol by such fires has not been included in the above estimates.

Gas, Oil and Urban Fires

In addition to the above mentioned fires there are also the effects of fires in cities and industrial centers, where huge quantities of combustible materials and chemicals are stored. As an example, if the European 95-day energy stockpile is roughly representative for the world (18), about 1.5×10^{15} g C fossil fuel (around 1.5 thousand million tons) is stored globally. Much of this would be destroyed in the event of a nuclear war. Therefore, if the relative emission yields of particulate matter by oil and gas fires are about equal to those of forest fires, similar rates of production of atmospheric aerosol would result. Although it may be enormously important, in this study we will not consider the global environmental impacts of the burning and release of chemicals from urban and industrial fires, as we do not yet have enough information available to discuss this matter in a quantitative manner.

Even more serious atmospheric consequences are possible, due to the many fires which would start when oil and gas production wells are destroyed, being among the principal targets included in the main scenario provided for this study (5). Large quantities of oil and gas which are now contained under high pressure would then flow up to the earth's surface or escape into the atmosphere, accompanied by huge fires. Of course, it is not possible for the nuclear powers to target all of the more than 600 000 gas and oil wells of the world. However, certain regions of the world where production is both large and concentrated in small areas are likely to be prime targets in a nuclear war. Furthermore, the blowout of a natural gas well results in the release of gas at a much greater rate than is allowed when under control and in a production network. For example, one of the more famous blowouts, "The Devil's Cigarette Lighter", occurred at Gassi Touil in the Sahara. This well released 15×10^6 m^3 of gas per day until the 200-meter high flame was finally extinguished by explosives and the well capped (19). Fewer than 300 such blowouts would be required to release natural gas (partly burned) to the atmosphere at a rate equal to present consumption. Descriptions of other blowouts such as the Ekofisk Bravo oil platform in the North Sea (20), a sour gas well (27 percent H_2S) in the province of Alberta, Canada (21) and the Ixtoc I oil well in the Gulf of Mexico (22) may be found in the literature.

As an example of how very few weapons could be used to release large quantities of natural gas, consider the gas fields of the

Netherlands. The 1980 production of 7.9×10^{10} m^3 of natural gas in Groningen amounted to 38 percent of that for all of Western Europe and 5 percent of that for the entire world (19). Most of the gas production in the Netherlands is concentrated in a field of about 700 km^2 area. It seems likely that a 300-kt nuclear burst would uncap every gas well within a radius of 1 km either by melting the metal pipes and valves, by snapping the pipes off at the ground by the shock wave, or by breaking the well casings via shock waves propagated in the earth. This is in consideration of the following facts (23): 1) the fireball radius is 0.9 km, 2) for a surface burst the crater formed is approximately 50 m deep and 270 m in diameter, 3) the maximum overpressure at 1 km is 3.1 atmospheres (atm), 4) the maximum dynamic pressure at 1 km is 3.4 atm, and 5) the maximum wind speed at 1 km is 1700 km/h. Considering then that a 300-kt bomb has a cross-section of greater than 3 km^2 for opening gas wells, fewer than 230 such weapons are required to cover the entire 700 km^2 Groningen field of the Netherlands. This amounts to less than 69 Mt of the 5750 Mt available for the Scenario I nuclear war.

Offshore oil and gas platforms might also be targets of a nuclear war. For example, in 1980 the United Kingdom and Norway produced 2.1×10^6 barrels of oil per day from a total of 390 wells (about 40 platforms) in the North Sea (19). Considering that a 100-kt weapon would be more than sufficient to destroy an offshore platform, only 4 Mt of explosive yield need be used to uncap these wells, which produce 3.5 percent of the world's petroleum.

One can point out many other regions of the world where gas and oil production is particularly concentrated. Production in the US is considerably more dispersed than in other countries, however. For comparison, in 1980 the US produced an average of 8.6×10^6 barrels of oil per day from about 530 000 wells whereas the USSR production was 12.1×10^6 barrels per day from only 80 000 wells (19). The oil and gas fields of the Soviet Union, particularly the oil producing Volga-Ural region and the gas and oil fields of the Ob region, are highly localized and particularly vulnerable to nuclear attack.

Much of the gas and oil released as a result of nuclear attacks will burn. This is another source of copious amounts of particulate matter in the atmosphere. However, it is also likely that a fraction of the gas would escape unburned to the atmosphere where it would be gradually broken down by photochemical reactions. Much of the escaping oil may likewise burn, but an appreciable portion of it may volatilize as in the Ixtoc I blowout in the Gulf of Mexico, which resulted in the world's largest oilspill. In this case it is estimated that only 1 percent of the oil burned, while 50–70 percent evaporated (22). We next consider the influence of these emissions on the gaseous composition of the atmosphere.

Natural gas consists usually of a mixture of 80–95 percent (by volume) methane (CH_4) and the remaining 5–20 percent heavier hydrocarbons, mainly ethane (C_2H_6) and propane (C_3H_8), and varying amounts of carbon dioxide and nitrogen. Current global consumption of natural gas amounts to about 10^{15} g of carbon per year, which is 20 percent of the total fossil fuel consumption rate (24). The current atmospheric content of ethane is equal to about 6×10^{12} g of carbon, based on observations indicating amounts of 1 ppbv (1 ppbv $=10^{-9}$ by volume) in the Southern and 2 ppbv in the Northern Hemisphere (25). Consequently the rapid release of C_2H_6 by blow-outs during a nuclear war

Abadan, Iran: oil refinery burns after Iraqi bombing. The damage is bad enough from conventional weapons. A nuclear bomb would have levelled everything in sight and the resulting fire storms would rage for weeks, blackening the entire sky. Photo: Pressens Bild.

BOX 2

Reaction Cycle C1. In the presence of sufficient NO the oxidation of CO to CO_2 results in the formation of ozone as follows:

R1 $CO + OH \rightarrow H + CO_2$
R2 $H + O_2 + M \rightarrow HO_2 + M$
R3 $HO_2 + NO \rightarrow OH + NO_2$
R4 $NO_2 + h\nu \rightarrow NO + O$
R5 $O + O_2 + M \rightarrow O_3 + M$

C1 $CO + 2\,O_2 \rightarrow CO_2 + O_3$

Reaction Cycle C2. The oxidation of methane in the atmosphere leads to ozone formation as follows:

R6 $CH_4 + OH \rightarrow CH_3 + H_2O$
R7 $CH_3 + O_2 + M \rightarrow CH_3O_2 + M$
R8 $CH_3O_2 + NO \rightarrow CH_3O + NO_2$
R9 $CH_3O + O_2 \rightarrow CH_2O + HO_2$
R3 $HO_2 + NO \rightarrow OH + NO_2$
R4 $NO_2 + h\nu \rightarrow NO + O$ (Twice)
R5 $O + O_2 + M \rightarrow O_3 + M$ (Twice)
R10 $CH_2O + h\nu \rightarrow CO + H_2$

C2 $CH_4 + 4\,O_2 \rightarrow CO + H_2 + H_2O + 2\,O_3$

Reaction Cycle C3. In the absence of sufficient NO in the atmosphere the oxidation of CO leads to ozone destruction as follows:

R1 $CO + OH \rightarrow CO_2 + H$
R2 $H + O_2 + M \rightarrow HO_2 + M$
R11 $HO_2 + O_3 \rightarrow OH + 2\,O_2$

C3 $CO + O_3 \rightarrow CO_2 + O_2$

can increase by many-fold the atmospheric concentrations of this gas, which has an atmospheric residence time of about two months. Similar conclusions can be drawn with regard to the higher hydrocarbons. Although relative increases of methane in the atmosphere will take place at a relatively slower pace—as its present atmospheric abundance is much larger, 3×10^{15} g of carbon—even here the atmospheric concentrations may multiply if a sufficiently large percentage of the gas wells are being destroyed. Once destroyed, it seems unlikely that quick repair can be possible in a chaotic world in which little expert personnel and equipment will be available, while the fields will furthermore be heavily contaminated with radioactivity.

Of course it is impossible to guess how many oil and gas well destructions would result from a nuclear war, how much gas will burn and how much will escape unburned to the atmosphere. As an example to indicate the atmospheric effects, let us assume that quantities of oil and gas will continue to burn corresponding to present usage rates, with 25 percent of the present production gas escaping unburned into the atmosphere. We do not know whether the latter assumption is realistic. If not the chosen conditions may represent a gross underestimate of the atmospheric emissions which could take place during and after a nuclear war. This is, of course, especially the case when the world's oil and gas production fields are targeted as foreseen in the main scenario of this study. We simulate NO_x emissions from oil and gas field fires with those provided by current industrial rates. This adds 20 Tg of nitrogen to the NO_x source from forest fires.

TROPOSPHERIC PHOTOCHEMISTRY

For the Scenario I nuclear war most of the bomb cloud remains in the troposphere. The sudden input of a large quantity of nitric oxide of 5.7×10^{35} molecules (12 Tg nitrogen) by nuclear explosions and the more gradual input of NO_x from forest fires and gas and oil well fires, mainly in the Northern Hemisphere, will cause important changes in the course of the photochemical reactions taking place. Of course, these reactions should occur only in regions where sufficient sunlight would still penetrate. Alternatively, these reactions begin to occur after an appreciable fraction of the aerosol loading of the atmosphere has diminished because of removal of the particulate matter by rain or dry deposition. The following discussion is, therefore, mainly aimed at illustrating the sort of photochemical effects that may take place. The presence of NO in the troposphere favors chemical processes leading to the production of ozone, *eg* during the oxidation of carbon monoxide (CO) and methane (CH_4), which are present at part per million levels as normal constituents of the troposphere. The production of ozone in these cases takes place with OH, HO_2, NO and NO_2 as catalysts via the cycles of reaction C1 and C2 shown in Box 2. Under present non-war conditions, it appears that a large fraction of the troposphere does not contain enough NO for ozone production to take place. For such conditions the oxidation of CO occurs instead via the reaction cycle C3 of Box 2. In contrast to reaction cycle C1, cycle C3 leads to ozone destruction. From a comparison of reaction cycles C1 and C3, it follows that ozone production takes place as long as the atmospheric concentration of NO exceeds 1/4000 that of O_3, which is the ratio of rate coefficients for the reactions R11 and R3 (26, 27). If enough NO were present everywhere in the troposphere for all atmospheric oxidation of CO and CH_4 to occur via reaction cycles C1 and C2, the globally averaged, vertical column integrated photochemical production of ozone in the troposphere would be much larger ($\sim 5 \times 10^{11}$ molecules/cm^2/s) than can be balanced by destruction at the earth's surface ($\sim 6 \times 10^{10}$ molecules/cm^2/s) and by photochemical removal via the reactions

R12 $O_3 + h\nu \rightarrow O(^1D) + O_2$

R13 $O(^1D) + H_2O \rightarrow 2\,OH$

which is estimated at 8×10^{10} molecules/cm^2/s (28, 29). Reactions R12 and R13 constitute the main pathway for the production of hydroxyl radicals (OH), which initiate many oxidation processes in the atmosphere.

BOX 3

Reaction Cycle C4. Atmospheric oxidation of ethane forms ozone as follows. The carbon monoxide (CO) produced may also be oxidized to form additional ozone via cycle C1.

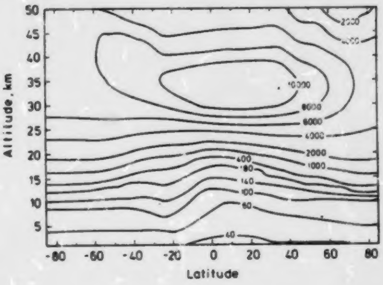
R14 $C_2H_6 + OH \rightarrow C_2H_5 + H_2O$
R15 $C_2H_5 + O_2 + M \rightarrow C_2H_5O_2 + M$
R16 $C_2H_5O_2 + NO \rightarrow C_2H_5O + NO_2$
R17 $C_2H_5O + O_2 \rightarrow CH_3CHO + HO_2$
R18 $CH_3CHO + OH \rightarrow CH_3(C{=}O) + H_2O$
R19 $CH_3(C{=}O) + O_2 + M \rightarrow CH_3(C{=}O)O_2 + M$
R20 $CH_3(C{=}O)O_2 + NO_2 + M \rightarrow CH_3(C{=}O)O_2NO_2 + M$
R21 $CH_3(C{=}O)O_2 + NO \rightarrow CH_3 + CO_2 + NO_2$
R7 $CH_3 + O_2 + M \rightarrow CH_3O_2 + M$
R8 $CH_3O_2 + NO \rightarrow CH_3O + NO_2$
R9 $CH_3O + O_2 \rightarrow CH_2O + HO_2$
R3 $HO_2 + NO \rightarrow OH + NO_2$ (2 times)
R4 $NO_2 + h\nu \rightarrow NO + O$ (5 times)
R5 $O + O_2 + M \rightarrow O_3 + M$ (5 times)
R10 $CH_2O + h\nu \rightarrow CO + H_2$

C5 $C_2H_6 + 10\,O_2 \rightarrow 2\,H_2O + H_2 + CO_2 + CO + 5\,O_3$

The photochemistry of the ethane and higher hydrocarbon oxidation in the atmosphere follows similar reaction paths as for methane, although reactions occur faster because of the higher reactivity of these molecules (27, 30). In the case of ethane, there can be a net production of five ozone molecules per ethane molecule consumed, if sufficient NO is present in the atmosphere. The cycle of reactions, cycle C4, that produces ozone from ethane is shown in Box 3. The compound peroxyacetylnitrate, $CH_3(C{=}O)O_2NO_2$, which appears in C4 is a strong phytotoxicant and air pollutant, better known by the acronym PAN (31). The compound, CH_2O, is formaldehyde and CH_3CHO is acetaldehyde.

Few observations of NO in the background atmosphere have been made, mainly due to the extreme difficulties which are involved in its measurement at low concentrations (32, 33). The hypothesis that ozone production may take place only in a relatively small fraction of the troposphere is in accordance with present estimations of the sources and sinks of tropospheric NO_x (34). According to this compilation, the tropospheric sources of NO_x are dominated by industrial activities. This could imply that the current concentrations of tropospheric ozone in the Northern Hemisphere are substantially larger than those which prevailed during pre-industrial times.

Figure 1. Ozone mixing ratios (ppbv, 1 ppbv = 10^{-9}) in the present atmosphere as calculated by the 2-D model for August 1.



We have modeled the atmospheric photochemistry following a Scenario I nuclear war under the illustrative assumptions listed above. A description of the computer model used in this work is provided in Appendix II. The mixing ratios of ozone in the present atmosphere as calculated by the unperturbed model for August 1 are provided in Figure 1, and these are in good agreement with the observations (35). The calculated ozone concentrations on August 1, 50 days after the start of the war, are shown in Figure 2. We notice the possibility of severe world-wide smog conditions resulting in high concentrations of ozone. With time, at midlatitudes in the Northern Hemisphere there may be large accumulations of ethane (50–100 ppbv) and PAN (1–10 ppbv).

EFFECTS OF TROPOSPHERIC COMPOSITION CHANGES

For Ambio's Scenario I type of war the most significant effects in the atmosphere will occur as a result of the wide variety of large fires, which affect especially military, urban and industrial centers, agricultural fields, oil and gas production areas, and forests. In the preceding section, we have considered a scenario of events which, in our opinion, represents probably the minimum of what may occur: wildfires in 10^6 km^2 of forests, and the burning and escape of oil and natural gas at rates comparable to present industrial usage. The estimated atmospheric effects are very large. The fires would create sufficient quantities of airborne particulate matter in the atmosphere to screen out a large fraction of the solar radiation for many weeks, strongly reducing or even eliminating the possibility of growing agricultural crops over large areas of the Northern Hemisphere. Dark aerosol deposits on the vegetation would likewise severely limit plant productivity. In addition, if the war should start during the summer months, as envisaged in the war scenario of this study, much cropland would be destroyed directly by fast-moving fires. Also of special concern are the heavy deposits of air pollutants from the atmosphere which would take place in the months during and following the war. If an appreciable fraction of the NO_x formed in the nuclear explosions and in the resulting fires were to be deposited in rain, the rainwater would be highly acidic with an average pH of less than 4.

If the production of aerosol by fires is large enough to cause reductions in the penetration of sunlight to ground level by a factor of a hundred, which would be quite possible in the event of an all-out nuclear war, most of the phytoplankton and herbivorous zooplankton in more than half of the Northern Hemisphere oceans would die (36). This effect is due to the fast consumption rate of phytoplankton by zooplankton in the oceans. The effects of a darkening of such a magnitude have been discussed recently in connection with the probable occurrence of such an event as a result of the impact of a large extraterrestrial body with the earth (37). This event is believed by many to have caused the widespread and massive extinctions which took place at the Cretacious-Tertiary boundary about 65 million years ago.

For several weeks following the war the physical properties of the Northern Hemispheric troposphere would be fundamentally altered, with most solar energy input being absorbed in the atmosphere instead of at the ground. The normal dynamic and temperature structure of the atmosphere would therefore change considerably over a large fraction of the Northern Hemisphere, which will probably lead to important changes in land surface temperatures and wind systems. The thick, dark aerosol layer would likely give rise to very stable conditions in the troposphere (below 10 km) which would restrict the removal of the many fire-produced and unhealthy pollutants from the atmosphere. Furthermore, fires also produce as many as 6×10^{10} cloud condensation nuclei per gram of wood consumed. The effect of many condensation nuclei is to narrow the cloud droplet size distribution and suppress formation of rain droplets by coalescence, probably leading to a decrease in the efficiency with which clouds can produce rain (38). The influence of large-scale vegetation fires on weather has been recognized by researchers for many years (eg 39). After the settling of most of the particulate matter, ozone concentrations over much of the Northern Hemisphere could approach 160 ppbv for some months following the war. With time, substantial increases in other pollutants such as PAN to several ppbv may also occur. These species are important air pollutants which are normally present in the atmosphere at much lower concentrations (~30 ppbv for ozone and less than 0.1 ppbv for PAN) (33, 40, 41).

The effects of ozone on public health and plant growth have been studied for several decades, especially in the US in connection with the Los Angeles basin photochemical smog problem. The effects on agricultural plants may be particularly severe. A major EPA report (31), listed several examples of decreases in yields of agricultural crops. For instance: "A 30 percent reduction in the yield of wheat occurred when wheat at antheses [blooming] was exposed to ozone at 200 ppbv, 4 hours a day for 7 days ... Chronic exposures to ozone at 50–150 ppbv for 4–6 hours a day reduced yields in soybeans and corn grown under field conditions. The threshold for measurable effects for ozone appear to be between 50 and 100 ppbv for sensitive plant cultivers ... An ozone concentration of 50 to 70 ppbv for 4 to 6 hours per day for 15 to 133 days can significantly inhibit plant growth and yield of certain species."

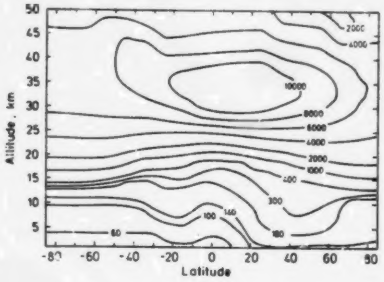
As a result of the nuclear holocaust we have indicated the possibility of an increase of average ground level ozone concentration to 160 ppbv with higher values to be expected in areas in the wake of the mix of forest and gas and oil well fires assumed in this study. It follows, therefore, that agricultural crops may become subjected to severe photochemical pollutant stress in addition to the even greater damaging effects due to the large load of aerosol particles in the atmosphere.

We conclude, therefore, that the atmospheric effects of the many fires started by the nuclear war would be severe. For the war scenario adopted in this study, it appears highly unlikely that agricultural crop yield would be sufficient to feed more than a small part of the remaining population, so many of the survivors of the initial effects of the nuclear war would probably die of starvation during the first post-war years. This analysis does not address the additional complicating adverse effects of radioactivity or synergism due to concomitant use of chemical and biological warfare weapons.

The described impacts will be different if a nuclear war starts in the winter months. Forest areas burned may be half as large (7), photochemical reactions would be slower because of less solar radiation and lower temperatures. However, in wintertime, because of the low sun, the darkness caused by the fire-produced aerosol would be much worse.

In this work little discussion could be devoted to the health effects of fire-produced pollutants. They too, no doubt, will be more serious in winter than in summer.

Figure 2. Ozone mixing ratios (ppbv) on August 1, 50 days after the beginning of the Scenario I nuclear war. Inputs from forest fires and oil and gas well fires as described in the text.



STRATOSPHERIC OZONE DEPLETION

In the stratosphere, molecular oxygen, O_2, absorbs solar radiation of wavelengths shorter than 242 nm and dissociates into two oxygen atoms. These oxygen atoms combine with two oxygen molecules to form two ozone molecules as follows:

$$\text{R14}\quad O_2 + h\nu \rightarrow O + O$$

$$\text{R5}\quad O + O_2 + M \rightarrow O_3 + M\ \text{(Twice)}$$

This formation mechanism is quite different from that described previously for the troposphere and summarized in cycles C1 and C2 of Box 2. Whereas oxides of nitrogen promote ozone formation in the troposphere, in the stratosphere, where the chemical composition and light spectrum are quite different, the effect of oxides of nitrogen is to catalyze ozone destruction via the reactions:

$$\text{R15}\quad NO + O_3 \rightarrow NO_2 + O_2$$

$$\text{R16}\quad O + NO_2 \rightarrow NO + O_2$$

$$\text{R17}\quad O_3 + h\nu \rightarrow O_2 + O$$

$$\text{Net:}\quad 2\,O_3 \rightarrow 3\,O_2$$

It is now recognized that this cycle is the principal means by which ozone is limited in the natural stratosphere (42). Also, whereas ozone is an undesirable pollutant in the troposphere, in the stratosphere ozone performs the necessary function of shielding the earth's surface from biologically damaging ultraviolet radiation.

Our model does not predict significant stratospheric ozone depletion for Ambio's reference Scenario I since as seen in Table 1, very little NO_x is deposited in the stratosphere for this scenario. However, for Scenario II (based on previous studies)—which considers the detonation of numerous weapons of large yield—the model predicts very large depletions. For this scenario the quantity of NO_x in the stratosphere of the Nothern Hemisphere is increased by a factor of approximately twenty above the natural level (21). The resulting large ozone depletions would begin in the Northern Hemisphere and eventually spread to the Southern Hemisphere. For purposes of illustration, the Scenario II nuclear war begins on June 11. The resulting ozone depletions on November 1 of the same year are shown in Figure 3. These large ozone depletions are consistent with the one-dimensional model results of Whitten, Borucki and Turco (2) and with the result of Chang as reported by the US National Academy of Sciences (1).

Whitten *et al* (2) considered total bomb yields in the range of 5000–10 000 Mt. They distributed the weapon yields either equally between 1-Mt and 5-Mt weapons or equally between 1-Mt and 3-Mt weapons. They also considered that the NO_x was either uniformly distributed throughout the Northern Hemisphere or spread uniformly between 30° and 70° N. Maximum depletion of the ozone column occurred two to three months following the NO_x injection and ranged from 35–70 percent. The 35 percent depletion occurred for the 5000 Mt total yield distributed equally between 1-Mt and 3-Mt bombs and spread uniformly over the entire Northern Hemisphere. The maximum of 70 percent depletion occurred for a total bomb yield of 10 000 Mt distributed equally between 1-Mt and 5-Mt explosions and confined to the region 30°–70° N. The time constant (e-folding time) for ozone recovery was approximately three years.

The NAS report (1) reaches similar conclusions. A 10 000 Mt war, confined to the Northern Hemisphere, is projected to result in a 30–70 percent ozone column reduction in the Northern Hemisphere and a 20–40 percent reduction in the Southern Hemisphere. Again, the characteristic recovery time was found to be approximately three years. Within ten years the ozone column depletions were estimated to have decreased to 1–2 percent.

Our two-dimensional model predicts a rather uniform 65 percent depletion of the ozone column spread from 45° N to the North Pole by the 50th day following the war. The depletions become less toward the equator and beyond, being 57, 42, 26, 12 and 1 percent at 35° N, 25° N, 15° N, 5° N and 5° S, respectively. As time progresses, the ozone depletions become less in the Northern Hemisphere, but NO_x is transported to the Southern Hemisphere and causes significant depletion there. Two years following the war in the Northern Hemisphere the ozone column depletions vary uniformly from 15 percent at 5° N to 56 percent at 85° N, with a 39 percent depletion of the ozone column at 45° N. At the same time ozone column depletions range from 12 percent at 5° S to 18 percent at 85° S in the Southern Hemisphere.

An important uncertainty in the model calculations for the stratosphere stems from the perturbations in the heating rates that accompany the large ozone depletions. Reduction of ozone causes a cooling of the stratosphere. By absorbing ultraviolet sunlight, ozone heats the atmosphere and causes the temperature inversion that is responsible for the high degree of resistance to vertical mixing. To a large extent the NO_x is partitioned into NO_2 in the stratosphere, and the absorption of solar radiation by this species also heats the stratosphere. We find that the net effect at midlatitudes in the perturbed stratosphere is heating below about 22 km and cooling above. The net heating below 22 km is due both to greater penetration of solar uv as a result of the reduced ozone column and the added heating in this region due to NO_2. This will undoubtedly affect the dynamics of the stratosphere and the temperature profile in the stratosphere in complex ways which we cannot predict. We can be confident, however, that the perturbation in the ozone column would be quite large for a Scenario II nuclear war.

Finally, we may point out that there is a possibility that even a nuclear war according to Scenario I, in which most NO_x is deposited in the troposphere, may cause ozone depletions in the stratosphere, if the hot fires in the oil and gas production regions become so powerful that the fire plumes penetrate into the stratosphere. Another means of upward transport may occur when the heavy, dark aerosol layer, initially located in the troposphere, is heated by solar radiation and starts to set up convection and wind systems which will transport an appreciable fraction of the fire effluents into the stratosphere. These speculative thoughts may be pursued further with currently available general circulation models of the atmosphere.

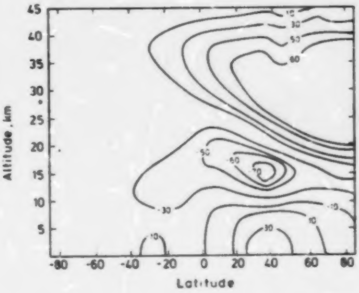


Figure 3. Atmospheric ozone depletion (%) on August 1 of the same year as the Scenario II nuclear war. Negative values indicate ozone increases and show the opposite effects of NO_x injections on ozone in the upper and lower regions of the atmosphere.

Past Nuclear Weapons Tests

In light of this discussion, one might naturally ask whether past nuclear weapon testing in the atmosphere resulted in significant ozone depletion. This topic has been the subject of considerable debate (43–52). That nuclear explosions produce copious quantities of nitric oxide and that multi-megaton bursts deposit this NO in the stratosphere was first recognized by Foley and Ruderman (44). The problem was presented as a possible test of whether NO_x from SST airplane exhaust would actually damage the ozone layer as suggested by Johnston (53) and Crutzen (54). The approximately 300 Mt of total bomb yield in a number of atmospheric tests by the US and USSR in 1961 and 1962 introduced about 3×10^{34} additional molecules of NO to the stratosphere. Using a one-dimensional model, Chang, Duewer and Wuebbles (49) estimated that nuclear weapon testing resulted in a maximum ozone depletion in the Northern Hemisphere of about 4 percent in 1963. Analysis of the ground ozone observational data for the Northern Hemisphere by Johnston, Whitten and Birks (45) revealed a decrease of 2.2 percent for 1960–1962 followed by an increase of 4.4 percent in 1963–1970. These data are consistent with the magnitude of ozone depletion expected, but by no means is a cause-and-effect relationship established. Angell and Korshover attribute these ozone column changes to meteorological factors (47, 48). The ozone increase began before most of the large weapons had been detonated and persisted for too long a period to be totally attributed to recovery from bomb-induced ozone depletion. Considering the large scatter in ozone measurements and our lack of understanding of all of the natural causes of ozone fluctuations, we cannot draw definite conclusions based on ground observations of ozone following the nuclear weapons tests of the late 1950's and early 1960's.

Solar Proton Events

From the previous discussion it is clear that we have no direct experimental evidence for stratospheric ozone depletion as a result of nuclear explosions. However, at least for altitudes above 30 km the sudden input of significant amounts of NO_x has clearly been shown to lead to large ozone destructions. In August 1972 a major solar proton event deposited large amounts of nitrogen oxides in the stratosphere, leading to ozone depletions poleward of about 60° N. The estimated ozone depletions calculated with a photochemical model were confirmed by satellite observations of stratospheric ozone (55).

EFFECTS OF INCREASED UV-B RADIATION

Ozone in the stratosphere serves as a protective shield against the harmful effects of solar radiation in the wavelength region 240–320 nm (10^{-9} meter). The flux of radiation in the wavelength region 290–320 nm ("uv-B" radiation) is particularly sensitive to very small changes in the ozone column (1). This biologically active radiation is also absorbed by the proteins and nucleic acids within living cells, resulting in a large variety of photoreactions and consequent cell damage (56–58).

The expected adverse effects of increased levels of uv-B radiation include increased incidence of skin cancer in fair-skinned races, decreased crop yields and a variety of stresses on terrestrial and aquatic ecosystems. Such effects have been considered in the past in connection with possible reduction of the ozone shield by the operation of fleets of SST airplanes (59) and by the continued release of chlorofluoromethanes used as refrigerants and as propellants in aerosol spray cans (60). The information available is insufficient to allow quantification of most of these effects. Epidemiological data were used in the NAS study (1) to estimate that a 50 percent ozone shield reduction lasting three years would lead to an increase of skin carcinoma and melanoma of 3 percent to 20 percent at midlatitudes, with a geometric mean of about 10 percent, that will persist for 40 years. This may be compared with the estimate made in the same study that during the first generation a 10 000 Mt war would increase the spontaneous cancer death rate by about 2 percent as a result of exposure to low levels of ionizing radiation from radioactive fallout.

Effects of increased uv-B radiation on food crops are extremely difficult to predict. The sensitivity of plants to supplemented uv-B has been found to be highly variable from one species to another. For example, whereas peas and onions are sensitive, more important food crops such as soybeans and corn appear to have a higher tolerance (1). Possible climatic changes following a nuclear war further complicate the picture for food crops. Crops are particularly sensitive to temperature, length of growing season and amount of precipitation. The coupling of significant changes in one or all of these factors with a change in the spectrum and intensity of light reaching the earth's surface could be particularly detrimental.

Reduction in stratospheric ozone and the concomitant increase in uv-B radiation would also stress natural ecosystems. As in agriculture, individual species of plants and animals differ considerably in their sensitivities to uv-B radiation. However, in natural ecosystems a direct effect on only one species may be propagated to a large number of species because of complex interdependences. For example, the food chain of the oceans is based on photosynthesis by phytoplankton, and these microscopic, green plants have been demonstrated to be quite sensitive to uv radiation (60). It was estimated from uv-B irradiation experiments that a 16 percent ozone reduction (the degree of ozone depletion projected by the NAS study for continued release of chlorofluoromethanes) could kill up to 50 percent of the anchovies in the top 10 meters of the clearest ocean water or else require them to substantially deepen their usual water depth (60, 61). Avoidance could provide protection for many animals, but it is thought that few species can sense uv-B light.

The "effective" increases in uv-B radiation may be determined by integrating the product of the uv-B radiation flux and the appropriate "action spectrum" over wavelength. We have computed these integrals using the action spectrum for erythema (sunburn). This action spectrum is very similar to the absorption spectrum of DNA, as are most uv-B action spectra, and thus the results apply rather generally to cell damage of all types (62). The relative increases in effective uv-B radiation are shown in Figure 4 for several latitudes as a function of time following the nuclear war. As noted earlier, the uv-B increases are extremely large and persist for several years. The Scenario II nuclear war initially would result in increases in uv-B radiation by a factor greater than 5 throughout most of the Northern Hemisphere and greater than 10 between 55° N and the North Pole. These large increases in uv-B radiation are expected to persist long after the attenuation of light by atmospheric aerosol produced by the nuclear blasts and by the many fires is no longer significant. By comparison, the projected increase in effective uv-B radiation for continued release of chlorofluoromethanes at 1977 levels is 44 percent (60).

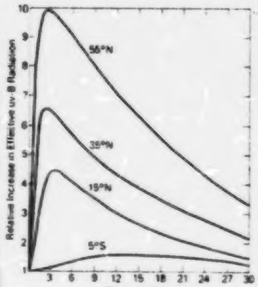


Figure 4. Relative increases in effective uv-B radiation based on the erythema action spectrum for the Scenario II nuclear war.

LONG-TERM EFFECTS

Regarding possible climatic effects, little can be said with confidence. The increase in tropospheric ozone, methane and possibly other pollutant gases may lead to increased temperatures at the earth's surface (63, 64), while the dark aerosol produced by the fires will change the heat and radiative balance and dynamics of the earth and the atmosphere for awhile. Longer lasting effects may be caused by the changes in the reflective properties of the land surfaces because of many fires. In a recent study Hansen *et al* (65) have been able to trace observed mean global temperatures over the past 100 years with a simple climate model by introducing changes in the atmospheric CO_2 content, volcanic activity and solar variability as the main driving forces. In their model the climate sensitivity was also tested for various global radiation perturbations which are relevant for this study: stratospheric aerosol, tropospheric aerosol (divided into opposite sulfate and soot effects), and atmospheric trace gas content (carbon dioxide, ozone, methane and nitrous oxide). From this study it is conceivable that climate could be sensitive over the short term to the tropospheric and stratospheric aerosol loading. It may be possible to test the impact of a nuclear war on climate with this and similar models, when these are supplied with reasonable estimates of the trace gas and aerosol composition of the earth's atmosphere. Whether the induced perturbation in the climate system could lead to longer lasting climatic changes will, however, be difficult to predict. In fact, it may seem unlikely that it will take place. The Krakatoa volcanic eruption of 1883 injected quantities of aerosol into the atmosphere comparable to those which would be caused by a nuclear war, and global mean temperatures were affected for only a few years (1). Still, we must be cautious with a prediction as the physical characteristics of the aerosol produced by volcanos and fires are different, and much is still unknown about the fundamentals of climatic changes. For instance, we may ask questions such as whether the earth's albedo would be substantially altered after a nuclear war and thus affect the radiation balance or whether the deposition of soot aerosol on arctic snow and ice and on the glaciers of the Northern Hemisphere might not lead to such heavy snow and ice melting as to cause an irreversible change in one or more important climatic parameters.

CONCLUSIONS

In this study we have shown that the atmosphere would most likely be highly perturbed by a nuclear war. We especially draw attention to the effects of the large quantities of highly sunlight-absorbing, dark particulate matter which would be produced and spread in the troposphere by the many fires that would start burning in urban and industrial areas, oil and gas producing fields, agricultural lands, and forests. For extended periods of time, maybe months, such fires would strongly restrict the penetration of sunlight to the earth's surface and change the physical properties of the earth's atmosphere. The marine ecosystems are probably particularly sensitive to prolonged periods of darkness. Under such conditions it is likely that agricultural production in the Northern Hemisphere would be almost totally eliminated, so that no food would be available for the survivors of the initial effects of the war. It is also quite possible that severe, worldwide photochemical smog conditions would develop with high levels of tropospheric ozone that would likewise interfere severely with plant productivity. Survival becomes even more difficult if stratospheric ozone depletions also take place. It is, therefore, difficult to see how much more than a small fraction of the initial survivors of a nuclear war in the middle and high latitude regions of the Northern Hemisphere could escape famine and disease during the following year.

In this paper we have attempted to identify the most important changes that would occur in the atmosphere as a result of a nuclear war. The atmospheric effects that we have identified are quite complex and difficult to model. It is hoped, however, that this study will provide an introduction to a more thorough analysis of this important problem.

APPENDIX I

Production and Spatial Distribution of Nitric Oxide From Nuclear Explosions

There have been numerous estimates (43–46, 66) of the yield of nitric oxide per megaton (Mt) of explosion energy, and these have been reviewed by Gilmore (66). Nitric oxide is produced by heating and subsequent cooling of air in the interior of the fireball and in the shock wave.

The spherical shock wave produces nitric oxide by heating air to temperatures above 2200 K. This air is subsequently cooled by rapid expansion and radiative emission, while the shock front moves out to heat more air. At a particular temperature the cooling rate becomes faster than the characteristic time constant for maintaining equilibrium between NO and air. For cooling times of seconds to milliseconds the NO concentration "freezes" at temperatures between 1700 and 2300 K, corresponding to NO concentrations of 0.3–2 percent. Gilmore (66) estimates a yield of 0.8×10^{32} NO molecules per Mt for this mechanism.

The shock wave calculation of NO production does not take into account the fact that air within the fireball center contains approximately one-sixth of the initial explosion energy, having been heated by the radiative growth mechanism described earlier. This air cools on a time scale of several seconds by further radiative emission, entrainment of cold air, and by expansion as it rises to higher altitudes. These mechanisms are sufficiently complex that one can only estimate upper and lower limits to the quantity of NO finally produced.

A lower limit to total amount of NO finally produced may be obtained by assuming that all of the shock-heated air is entrained into the fireball and again heated to a high enough temperature to reach equilibrium. This is possible since the thickness of the shell of shock-heated air containing NO is smaller than the radius of the fireball. To minimize the cooling rate, and thus the temperature at which equilibrium is not re-established rapidly, it is assumed that this air mass cools only by adiabatic expansion as the fireball rises and by using a minimum rise velocity. The resulting lower limit to total NO production is 0.4×10^{32} molecules per Mt (66).

Since the interior of the fireball is much hotter than the surrounding, shock-heated air, it will rise much faster and possibly pierce through the shell of shock-heated air to mix with cold, undisturbed air above it. Thus, an upper limit to NO production may be obtained by assuming that none of the 0.8×10^{32} NO molecules per Mt produced in the shock wave are entrained by the hot fireball interior. Instead, one assumes that the interior is cooled totally by entrainment of cold, undisturbed air to produce additional NO. The upper limit to total NO production is then estimated to be 1.5×10^{32} molecules per Mt (66). Thus, the range of uncertainty for total NO_x formation is $0.4–1.5 \times 10^{32}$ molecules per Mt.

For the purposes of this study we assume a nitric oxide yield of 1.0×10^{32} molecules per Mt. One can make strong arguments against either of the extreme values. This estimate of NO production applies only to detonations in the lower atmosphere.

In a nuclear war some bombs may be exploded at very high altitudes for the purpose of disrupting radio and radar signals. The ionization of air by gamma rays, X-rays and charged particles creates a phenomenon known as the "electromagnetic pulse" or "EMP" (67). The partitioning of energy between the locally heated fireball, shock wave, and escaping thermal radiation changes dramatically as the altitude of the explosion increases above 30 km. As the altitude increases, the X-rays are able to penetrate to greater distances in the low density air and thus create very large visible fireballs. For explosions above about 80 km, the interaction of the highly ionized weapon debris becomes the dominant mechanism for producing a fireball, and for such explosions the earth's magnetic field will influence the distribution of the late-time fireball. Explosions above 100 km produce no local fireball at all. Because of the very low air density, one-half of the X-rays are lost to space, and the one-half directed toward the earth deposits its energy in the so-called "X-ray pancake" region as they are absorbed by air of increasing density. The X-ray pancake is more like the frustum of a cone pointing upward, with a thickness of about 10 km and a mean altitude of 80 km. The mean vertical position is essentially independent of the explosion altitude for bursts well above 80 km (67).

The absorption of X-rays by air results in the formation of pairs of electrons and positively charged ions. One ion pair is formed for each 35 eV of energy absorbed (68), and in the subsequent reactions approximately 1.3 molecules of NO are produced for each ion pair (69). A 1-Mt explosion corresponds to 2.6×10^{34} eV of total energy. Thus, considering that only half of the X-rays enter the earth's atmosphere, the yield of NO is calculated to be 4.6×10^{32} molecules per Mt (ie this mechanism is about five times more effective at producing NO than the thermal mechanism described above).

In the course of a nuclear war up to one hundred 1-Mt bombs might be detonated in the upper atmosphere for the purpose of creating radio wave disturbances. The injection of NO would therefore be 4.8×10^{34} molecules or 1.1 Tg of nitrogen. Natural production of NO in the thermosphere due to the absorption of EUV radiation depends on solar activity and is in the range 200–400 Tg of nitrogen per year (34). Thus the amount of NO injected by such high altitude explosions is about equal to the amount of NO produced naturally in one day and falls within the daily variability. In addition, the X-ray pancake is positioned at an altitude where nitrogen and oxygen species are maintained in photochemical equilibrium. Excess nitric oxide is rapidly destroyed by a sequence of reactions involving nitrogen and oxygen atoms as follows:

$$\begin{array}{ll} \text{R22} & NO + h\nu \rightarrow N + O \\ \text{R23} & N + NO \rightarrow N_2 + O \\ \hline \text{Net:} & 2\,NO \rightarrow N_2 + O + O \rightarrow N_2 + O_2 \end{array}$$

For these reasons, we expect that high altitude explosions of such magnitudes will have no significant global effect on the chemistry of the stratosphere and below.

Results of past tests of nuclear explosions show that nuclear clouds rise in the atmosphere and finally stabilize at altitudes that scale approximately as the 0.2 power of bomb yield. An empirical fit to observed cloud geometries at midlatitudes gives the following expressions for the heights of the cloud tops and cloud bottoms, respectively (44):

$$H_T = 22Y^{0.2}$$
$$H_B = 13Y^{0.2}$$

where H is in kilometers and Y has units of megatons. Thus, bomb clouds from weapons having yields greater than about 1 Mt completely penetrate the tropopause at midlatitudes. For such explosions all of the NO_x produced in the fireball, and perhaps a significant fraction of that produced in the shock wave but not entrained by the bomb cloud, is deposited in the stratosphere. Oxides of nitrogen formed in nuclear explosions having yields less than 1 Mt have little effect on stratospheric ozone since: 1) only a minor fraction of the NO_x formed is deposited above the tropopause, 2) the residence time in the stratosphere increases with altitude of injection, and 3) the NO_x-catalytic cycle for ozone destruction is most effective at higher altitudes. In fact, below about 20 km NO_x additions to the atmosphere tend to result in ozone concentration increases (70, 71).

The stabilized nuclear bomb clouds have diameters ranging from 5[illegible] to 500 km depending on bomb yield. They are sheared by horizontal winds at constant latitude, and within a few weeks may be uniformly distributed around the earth at a constant latitude (72).

APPENDIX II

Model Description

The computer model used in this study is a two-dimensional model of coupled photochemistry and dynamics. It treats transport in both the vertical and latitudinal directions by parameterization of these motions by means of eddy diffusion coefficients and mean motions. The model covers altitudes between the ground and 5[illegible] km and latitudes between the South Pole and North Pole, and it attempts to simulate the longitudinally averaged, meridional distributions of trace gases. Therefore, the main assumption is that composition variations in the zonal (East–West) directions are much smaller than those in the vertical and latitudinal directions. Although the 2-D model is a step forward from 1-D models, which take into account only variations in the vertical direction, the neglect of longitudinal variations in air composition will clearly introduce substantial deviations from reality, especially at lower altitudes, where the influence of chemical and biological processes at the earth's surface are large. One should keep these limitations of the 2-D model in mind especially when interpreting the results obtained for the troposphere.

The model photochemistry considers the occurrence of nearly one hundred reactions, which are now thought to be important in global air chemistry. It takes into account the reactions of ozone and atomic oxygen, and the reactive oxides of nitrogen, hydrogen and chlorine, which are derived from the oxidation of nitrous oxide (N_2O), water vapor (H_2O), methane (CH_4) and organic chlorine compounds. In the troposphere, the photochemistry of simple reactions leading to ozone formation in the presence of NO_x, carbon monoxide (CO), methane and ethane (C_2H_6) are taken into account. The influence of industrial processes is an important consideration of the model. A more detailed description of the model may be found elsewhere (71, 72). Detailed descriptions of atmospheric photochemistry are given in a number of review articles (34, 73–75).

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76 The authors are especially thankful to the following scientists for critically reading earlier versions of this article and providing us with advice in their various fields of expertise: Robert Charlson, Tony Delany, Jost Heintzenberg, Rupert Jaenicke, Harold Johnston, Chris Junge, Jeffrey Kiehl, Carl Kisslinger, James Lovelock, V Ramanathan, V Ramaswamy, Henning Rodhe, Steven Schneider, Wolfgang Seiler, Robert Sievers, Darold Ward, Ellen Winchester, Jack Winchester and Pat Zimmerman

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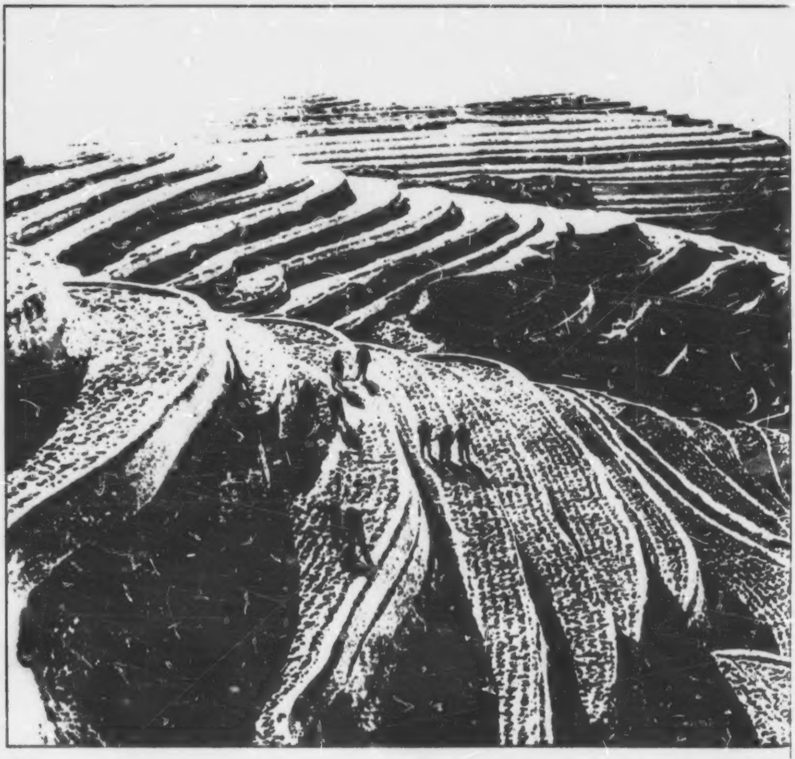
Ambio 1982

Effects on Agriculture

BY ERNEST A BONDIETTI

Radioactive contamination of croplands would be widespread in the Northern Hemisphere. And delayed fallout, in areas not directly involved in the war, would raise radioactivity levels in food and human tissues to 20 times the levels reported during the weapons' testing period of the 1960s. Agriculture would revert to a non-mechanized age and many Third World countries, dependent on enormous imports of food from the developed countries, would be severely affected.



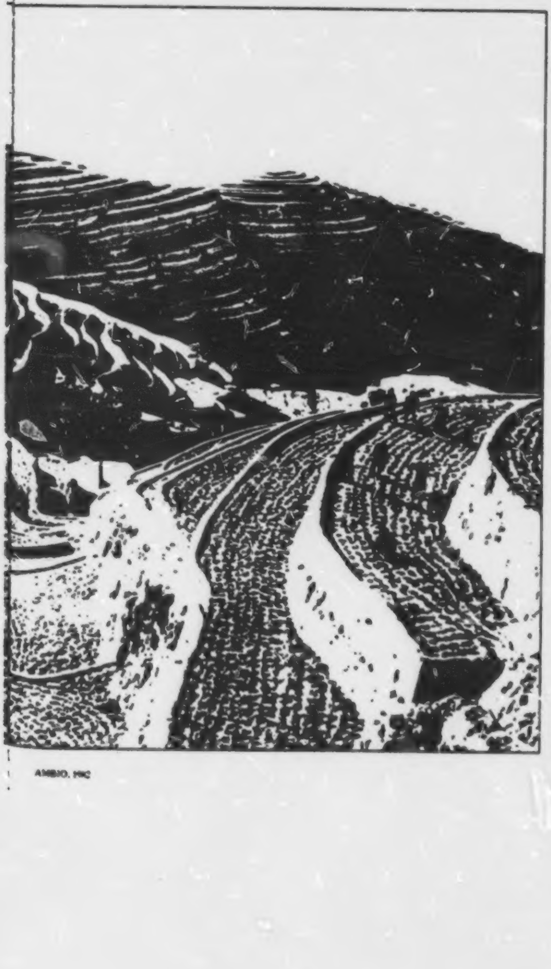
A global nuclear war will affect the world's agriculture in many diverse ways. Among the impacts of major concern will be:

1) High levels of radionuclides in food, especially in the Northern Hemisphere;
2) Destruction of the industrial infrastructure upon which mechanized agriculture depends;
3) Decreases in crop yields because of disruptions in pest control, plant breeding, and other productivity management techniques;
4) Failure of national and international food distribution/processing systems;
5) Decreases in crop yields because of large scale changes in atmospheric composition and climate.

The immediate effects on human beings of the June 1985 attacks described by the Reference Scenario (1), upon which this article is based, will be so catastrophic that in many ways all subsequent effects become trivial. Nevertheless, everyone not killed by blast, thermal, or early radiation exposure will be immediately faced with a drastically altered social and physical environment. Shelter, food, and medical needs will be of paramount concern. This article, however, will consider only the short- and long-term agricultural situation, especially the contamination of food with radioactivity.

For a large portion of the population living in the downwind areas blanketed by nonlethal levels of fallout from targets, the external radiation dose received during the first month or so will dominate the dose accumulated over their lifetimes from the eventual global deposit of radioactivity from the war. Most of the discussion of this globally dispersed radioactivity will concern dietary contamination although external radiation exposure will result in doses comparable to those derived from the diet (2, 3).

In order to illustrate the short-term and long-term role of diet in radiation exposure, the contamination of the Northern Hemisphere will be discussed from two perspectives. First, the local effect of a radioactive deposit downwind from the detonation of 1 megaton (total) is discussed; second, the effect of the fission product deposit on the Northern Hemisphere originating from that fraction of the total megatonnage used in the war which would be injected into the stratosphere. Since dietary habits following the war are hard to predict, the anticipated contamination of humans by their diet is based on present patterns of food consumption.



EARLY RADIOACTIVE FALLOUT

When a nuclear weapon is detonated at ground level, large amounts of surface materials are pulled up into the ascending fireball. Most of this debris immediately begins to fall back to earth. Those particles (and associated radioactivity) larger than about 20 microns in diameter which will be deposited in about one day are considered early or local fallout. Particles smaller than this will tend to stay in the troposphere for longer periods of time and may actually be injected into the stratosphere. For this article it is assumed that 50 percent of the fission yield (fission yield is assumed to be 50 percent of total megatonnage) will be deposited as early fallout; the remainder enters the stratosphere where its mean residence time is one year (2). This latter radioactivity constitutes the global fallout resulting from high-yield nuclear explosions.

Figure 1 represents an idealized early fallout pattern for strontium-90 deposition, in units of curies (Ci)/km^2, within about 500 km of ground zero. For this example, an area in central France was chosen to provide a perspective of the area contaminated by a surface detonation. Similar deposits could occur downwind from other targets. The isopleths of strontium-90 deposition were estimated by converting dose rates (R/hr) to deposit concentrations for a 1 megaton detonation (4, 5, 6). Up to about 150 km, the strontium-90 deposit could be $\geq$1.5 Ci/km^2, while at more than 400 km the deposit would be about 0.15 Ci/km^2. This deposition pattern was constructed in terms of strontium-90 for comparison to the global deposit of strontium-90. Shorter-lived radioisotope levels would be much greater; for example iodine-131 would be 1700 times higher at the time of detonation (4), assuming no fractionation of the radioactivity.

The 150 km distance delineated by the 1.5 Ci/km^2 isopleth in Figure 1 will be the region where absorbed doses (greater than 450 rads) accumulated over the first 24 hours after detonation could be fatal to humans and livestock. In this high dose region, crop yield reductions might also be expected. For example, maize is very sensitive to radiation during the first two months of growth, with almost complete loss of yield from a 2500 rad (gamma) exposure delivered over 8 hours (7). At the same dose rate, soybean yields were reduced between 10 and 50 percent, depending on exposure date, during the first two months of growth (7). The doses delivered by beta radiation to fallout-contaminated vegetation can be higher by a factor of 10 over the gamma dose because of the relatively short range of beta particles (8). Beta radiation will also cause skin lesions to develop on livestock contaminated with sub-lethal amounts of fallout and may cause injury to the gastrointestinal tract when contaminated foliage is eaten (9). These lesions would cause additional mortalities because of the higher bacterial infection rates which are a direct result of the marked reduction in the immune response capability of radiation-exposed mammals.

The early fallout, because of its large size ($\geq$20 μm), is much less available to organisms than the finer-sized global deposit (3). Also, the early fallout does not tend to remain on plant surfaces because of its coarse size, further reducing its entry into food chains (3). Despite this relatively low biological availability, the deposition of early fallout onto pastures can pose an important hazard because of the contamination of milk with iodine-131 and other fission products. Figure 2 illustrates the 30 day behavior (hypothetical) of ^{131}I, ^{90}Sr, and ^{137}Cs radionuclide contamination in milk along the 0.5 Ci/km^2 ^{90}Sr isopleth of Figure 1. The milk concentrations were estimated using calculations in reference 10, and assuming that 2.5 percent of the local deposit remained on pasture plants and was available for biological absorption by grazing cows. Iodine-131 (8 day half-life) is by far the most important nuclide because of its high fission yield, rapid entry into milk, and accumulation in the human thyroid gland. During the first week after deposition, ingestion of one liter of this milk could result in an infant thyroid dose of about 200 rem (2). This dose greatly exceeds the 1.5 rem non-occupational maximum recommended by the International Commission on Radiological Protection (10). It is comparable to the reference dose used by the US Nuclear Regulatory Commission during site licensing to establish the population exclusion boundary for a design basis nuclear reactor accident (11).

The external dose to farm workers at this location will be high, initially dominated by ^{140}Ba, ^{131}I, ^{131}Ce, ^{95}Zr as well as activation products like ^{239}Np and ^{237}U. The resulting whole body dose (greater than 200 rem in the first year) would be greatly in excess of current international standards for occupational exposure.

Strontium-90 and cesium-137 will be the most important dietary nuclides after about one year because most other radionuclides decay more quickly and are generally not as biologically available to plants from soil (2,5). The radiological importance of other fission products in the diet during the immediate post war period is not enough to warrant discussion here.

GLOBAL OR LATE RADIOACTIVE FALLOUT

On the average about 0.3 Ci/km^2 (^{90}Sr) and 0.4 Ci/km^2 (^{137}Cs) will eventually be deposited on the Northern Hemisphere. This will result from the tropospheric and stratospheric injection of these two radionuclides corresponding to about 1600 megatons of fission yield from air bursts (100 percent injected) and ground bursts (50 percent injected). This quantity is about 23 times the stratospheric inventory present at the beginning of 1963 following the Test Ban Treaty (2). Extensive monitoring through 1968, the year of the next atmospheric test, allows a direct scaling of dietary contamination data obtained from this period to the post-war period. The inventory of the stratosphere will deplete at a rate of about 50 percent per year, taking about 7 years for 99 percent of the fission products to be deposited on the Northern Hemisphere. Most of the ^{90}Sr and ^{137}Cs in the diet during the first half of this period will result from direct deposition of the fine global fallout particles on vegetation surfaces—pastures (milk, meat), cereals and vegetables. Only after about three years will the uptake of radionuclides through plant roots begin to

Figure 1. Idealized deposition pattern of ^{90}Sr from the early fallout of 1 megaton of weapons detonated at ground level. Contamination levels calculated assuming a 25 km/hr wind and that 1 Ci ^{90}Sr/km^2 is equal to a total gamma dose rate of 100 R/hr, calculated at a unit time (1 hr) after detonation (4, 5, 6).

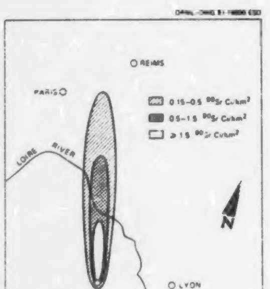
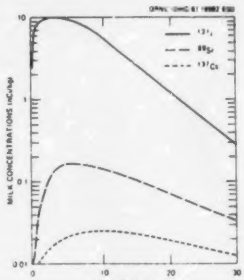


Figure 2. Hypothetical contamination levels in milk for ^{131}I, ^{137}Cs, and ^{90}Sr deposited on pastures about 300 km downwind from 1 megaton surface detonations. Trends with time scaled from the analysis in reference 10, assuming that 2.5 percent of the deposit was biologically available.



dominate the contamination of food (2, 6, 12). During the immediate post-war period, much of the area significantly contaminated by the local fallout deposits may actually produce food whose primary source of contamination is the annual global deposit. For the idealized local ^{90}Sr deposit illustrated in Figure 1 as an example, the annual total global deposit would probably dominate food contamination at least in all of the area outside the 1.5 Ci/km^2 isopleth, and probably more of the inside area. This dominance of food contamination is due to the longer period of direct deposition and the higher solubility of the global deposit (2,6). Therefore, areas contaminated by local fallout may not necessarily have to be restricted from producing food, although the higher levels of external gamma radiation would increase the radiation hazards to cultivators. The magnitude of the global fallout relative to the local fallout may seem incongruous; however it is a direct result of the intense targeting of population and military targets in the Northern Hemisphere.

Dietary Components

Food chain contamination from global fallout can be illustrated by scaling (upward) measured 1963–1973 levels in foodstuffs (2, 12, 13) by a factor of 23, with approximate corrections for post-1968 atmospheric test inputs. Examples of this scaling for milk, wheat, and beef are illustrated in Figure 3, an 11-year representation of possible foodstuff levels following the war. Concentrations of radiostrontium and radiocesium will be highest in the first year and decline thereafter. The rapid decline during the first few years represents the corresponding depletion of the stratospheric inventory; the stabilizing levels in beef and milk after this period reflect the increasing influence of root uptake over direct foliage contamination as the cumulative deposit increases. Radiocesium will behave differently than radiostrontium with time because in most temperate zone soils, illitic clay minerals immobilize cesium, reducing plant availability (14). The result is that the cumulative deposit in soil becomes a significant dietary contributor of ^{90}Sr sooner than for ^{137}Cs as the annual global deposition rate from global fallout declines. This is illustrated in Figure 3 for milk and wheat. Until about 1991, ^{137}Cs will dominate ^{90}Sr (as a result of its higher abundance in fallout); after this period the lower soil availability of ^{137}Cs makes ^{90}Sr the more abundant nuclide in the foodstuffs. A discussion of the reasons for the differences in radionuclide behavior between tilled soils (wheat) and pastures (beef, milk) is available elsewhere (3, 13, 15). It is also evident from Figure 3 that cultural dietary habits will influence ^{90}Sr and ^{137}Cs intakes. However, worldwide studies generally show remarkably similiar annual intakes except in unusual cases (2).

Diet and Body Burdens

Figure 4 represents the observed behavior of ^{137}Cs and ^{90}Sr in adults and their diet (2, 12) scaled to the post-war period. The diet is typical of "western" cultures; that is, high in milk and milk products. The whole body calculations were based on an adult containing 1050 g of calcium (Ca) and 140 g of potassium (K) since most fallout measurements are given as ^{90}Sr/g(Ca) and ^{137}Cs/g(K) in biological tissues (2). It is apparent that ^{137}Cs in the body (mostly in muscle tissue) follows the diet quite closely. This is because the biological half-life of most of the cesium in humans is only a few months (2). Based on Figure 4 and Northern Hemisphere fallout data (2), the total ^{137}Cs body burden will be about 100 times that of the daily diet. In contrast to ^{137}Cs, radiostrontium has a much longer turnover time in adults (about 30 percent per year) because it deposits mostly in bone tissue (2). Younger children can accumulate about twice as much ^{90}Sr (on a unit calcium basis) as adults because of new bone growth. However, this ^{90}Sr is also eliminated faster because of a faster bone turnover rate (2). The trends illustrated in Figure 4 are for high milk and milk product diets; high meat diets would have more ^{137}Cs and lower ^{90}Sr.

There can be notable exceptions to these patterns arising when dietary habits or soil properties differ significantly from the typical temperate zone case. The lichen-reindeer-man food chain of arctic and subarctic regions will result in ^{137}Cs burdens about two orders of magnitude above the middle latitude estimates of Figure 4 (2, 16). In contrast to the changing ^{137}Cs to ^{90}Sr relationship in milk illustrated by Figure 3, certain soil properties (acidic, low illitic clay content) can allow much higher ^{137}Cs levels to occur in milk or meat, resulting in high ^{137}Cs body burdens. This pat-

Figure 3. Theoretical trends of ^{90}Sr and ^{137}Cs in components of the human diet, resulting from global fallout on agricultural regions not highly contaminated by local fallout. Direct deposition dominates the first few years, while root uptake is important only after most of the fallout has ceased.

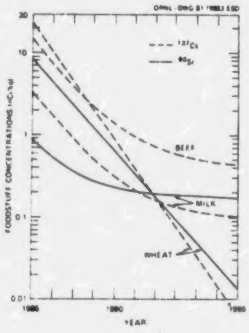
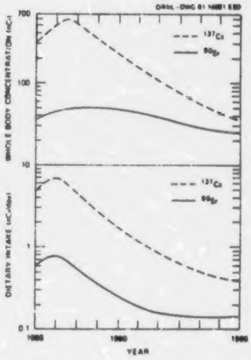


Figure 4. Comparisons of the behavior of ^{90}Sr and ^{137}Cs in the adult body and in diet during the post-war period. Whole body ^{90}Sr represents mostly bone deposition.



tern was identified both in the Faeroe Islands (13) and the Ukrainian Polessye region of the Soviet Union (17) and accounted for a 10 to 100 fold increase in ^{137}Cs body burdens over expected middle latitude levels. Elevated dietary levels of ^{137}Cs have also been noted in southern Florida, the tropics, and in regions of Norway because of poor soil fixation of cesium (2, 17).

The transuranium elements, tritium, ^{129}I, and ^{14}C will also enter the food chain. However compared to ^{137}Cs and ^{90}Sr, their dose contribution is small (2).

The preceding discussion of radioactivity in the diet was presented to illustrate the levels and modes of contamination occurring after the global nuclear war. The overall dose commitment to the survivors is discussed in a separate article (18). However, it can be estimated that diet will contribute about half the lifetime bone exposure resulting from global fallout, and that the lifetime dose commitment from dietary intake will be about 50 percent of the average lifetime background dose before the war, using the weapons'-testing fallout studies for calibration (2).

NON-RADIOLOGICAL CONSEQUENCES

Although most of this article has been concerned with radioactive contamination of the world's food supply, there are other effects which, in the short term, will impact the survivors far more severely. A June war will find grain stocks at low levels since the 1985 crop will have been planted only about one month earlier. Transportation disruptions will cause major imbalances in the population-food supply relationship and will force urban migration to rural areas. The social and physical consequences of this massive food supply imbalance are hard to evaluate, although the minimal result will be a large population dispersal. This dispersal, when coupled with heavy population losses in urban centers, would compensate for the reduced productivity (output per farmer) which would occur because of fuel, fertilizer, and pesticide shortages. Much of the 1985 grain harvest may have to be done by hand rather than by machine.

Loss of visible light caused by the large amounts of fine particles injected into the atmosphere by surface detonations would seriously affect agricultural productivity (see Crutzen and Birks, this issue). If a nuclear war depletes the ozone layer, the increased ultraviolet radiation would also affect crop yields and genetic mutation rates (19).

Effects on the Third World

As a result of the war food-importing countries not severely impacted by the war will suffer an almost complete cut-off of food from the major exporting nations. North America, for example, which supplies the majority of food aid to the Third World (20), would be unable to harvest and ship the 1985 crop. The length of this food cut-off would depend on the recovery of fuel refinery, rail, and port facilities. Thus a grain surplus (possibly unharvested) would exist in the US during 1985, but not thereafter. The effects of this cut-off on the Third World will vary, but if it occurred at the same time as a major natural catastrophe (eg. drought or insect plague) then the consequences could be enormous. The dependence of many Third World countries on agricultural technology from the industrialized North will create problems when the industrial nations are devastated. For example, hybrid seedstocks have become extremely important throughout the world for reasons related to disease resistance and higher yield per hectare. Any disruption in the capacity to produce these seeds will have enormous short-term repercussions for food production. Likewise, the control of insect plagues like the desert locust has become heavily dependent on chemicals produced in the industrial countries. The true magnitude of the effect of a cutoff in the support that advanced agricultural nations give to food-deficient nations is hard to evaluate but it could be catastrophic in some cases. Thus it is entirely possible that the disruption in trade may overwhelm the direct impact of radioactive contamination (see article: "Economic Effects: Back to the Dark Ages").

CONCLUSION

In the period immediately following the nuclear war, the inventory of growing food may be greater than the ability of the post-attack harvest and distribution systems to deliver it. Surviving populations may have to relocate closer to sources of production. Meat, milk, and green vegetables would be a prime source of food for several years, as the agricultural economy reverts to a less specialized scale. For both industrial and aid-dependent Third World countries, the food struggle will involve shortages and readjustments in cultural practices. Faced with shortages, radioactivity levels in the diet will not be a factor governing food allocations, especially since the global fallout insures that most of the production is uniformly contaminated. In fact, the increased radiation doses received by survivors may be the least detrimental aspect of the post-war existence, although considerable space was devoted to the levels of radioactivity in diet because of their predictability. It is certain, however, that millions may eventually suffer premature deaths caused by malnutrition, diseases, and chronic radiation exposure, and that many of these people will be in countries not involved in the ideological struggle which precipitated the war.

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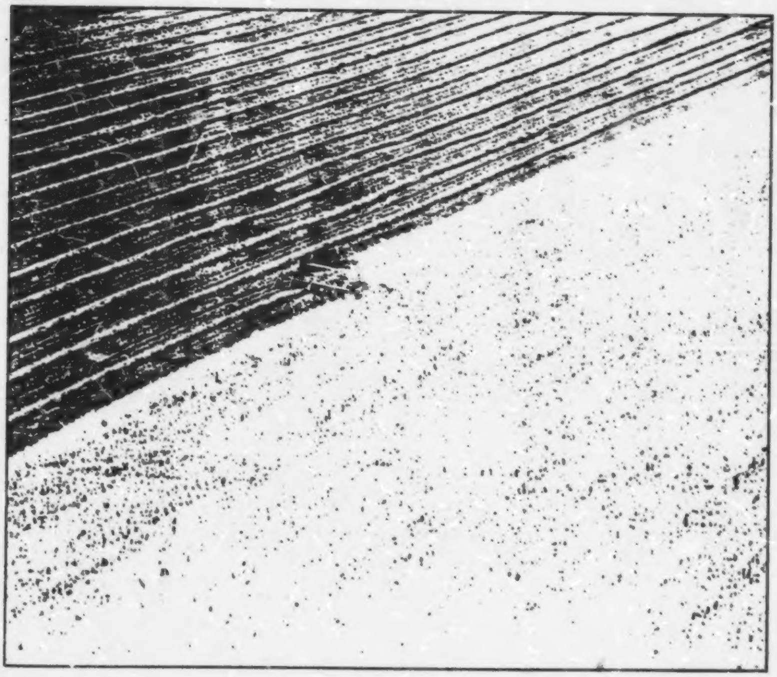
Ambio 1982

The Impact on Global Food Supplies

BY HOWARD W HJORT

Agricultural practices would revert to those of the 19th Century, with mostly human and animal power to till the soil and harvest crops. The tremendous number of deaths in the Northern Hemisphere, both human and animal, would lower the need for food and the production of animal products. Still, survivors would have to move to the food areas that remained. And millions would perish in the developing world because of the breakdown of the world food trade.

The countries likely to suffer the most damage in a nuclear war house one quarter of global population, but produce from 50 to 65 percent of the world's cereals. However the highly mechanized methods which account for such high productivity would be impossible after a nuclear war. Not only would crops be destroyed, but agriculture would revert to the traditional techniques of the 19th century, greatly reducing food production. Photo: National Film Board of Canada.



The world food system has been subjected to considerable shocks before, during wars and when weather reduced production. But prior experience is of only limited use in assessing the impact of a nuclear war of the magnitude outlined in the Reference Scenario (1), because the shock to the world food system would be so much more massive.

Other articles in this issue treat the effects of a global nuclear war on population, the economy, the atmosphere, freshwater and ocean systems, terrestrial ecosystems, and agricultural systems. These studies have important implications for the global food system; however, the full impact of a nuclear war on global food supplies is essentially beyond comprehension, or at least is not subject to precise quantification. It is the summation of a number of lesser impacts, some of them direct, others indirect.

The essential element in any estimate of global food supplies following a nuclear war is the destruction of people in relation to the destruction of animals and crops. Food stocks will no doubt be damaged and extensive croplands rendered radioactive. Furthermore, problems of distribution will almost certainly result in pockets of starvation in regions where local supplies are inadequate.

In this paper, the proportion of the human population which would survive in each region has been estimated by comparing population densities with the map of likely targets which accompanies the Reference Scenario. The damage to food production from blast, fires and initial fallout was estimated by comparing the target maps with maps showing crop and animal densities. The damage to agriculture due to global fallout was estimated by comparing the estimates given in Table 2 of the Reference Scenario with data on the patterns of global agricultural production.

PREVIOUS STUDIES

Previous studies on the relative vulnerability of population and agriculture are helpful in guiding judgments about the relative decline in the production of food. Brown (2) believes that agriculture in the United States is approximately as vulnerable to a nuclear attack as is population. He calculated survival rates following a 1300 Mt nuclear attack at about 80 percent for humans, 70 percent for milk cows, 75 percent for beef cattle, and 76 percent for swine. He also concluded that about 85 percent of the corn and soybeans, 75 percent of the potatoes and sugar beets, and 65 percent of the wheat would survive a June 15 attack. He also presented convincing evidence that June 15 would be at or near the most vulnerable time for crops produced in the United States.

However Neal (3) concluded that a severe food shortage would exist in the United Kingdom after a nuclear exchange. In an attack in which an estimated 75 percent of humans would survive, an estimated 64 percent of sheep, 67 percent of dairy cattle, 68 percent of beef cattle, and 72 percent of pigs also survived, assuming the animals were sheltered; for unsheltered animals the survival rates were 53 to 55 percent for sheep and cattle and 69 percent for pigs. The lack of experimental data on the impact of beta radiation on crops forced him to give a wider range for damage to crop yields. He concluded that cereal crop yields would be reduced by 25–50 percent, pasture production about 25 percent, and potato yields only slightly. Neal also noted that, assuming a June attack, cereal stocks would be quite low, which would add to short supply problems.

Findings from a large number of experiments conducted to determine the sensitivity of animals and plants to radiation were reported in 1971 (4). The findings of particular interest to this assessment are these:

- Poultry are more resistant to radiation than swine, and swine more resistant than cattle and sheep, especially if the latter are on pasture.
- Poultry are appreciably less sensitive than humans, swine a little less sensitive, cattle and sheep about as sensitive when in pens and barns, but considerably more sensitive when on pasture.
- Resistance to radiation effects has been found in sheep and swine, with the resistance quite long lasting in the latter.
- Relatively little negative impact has been found on animal productivity, but beta irradiation of the gastrointestinal tract of cattle and sheep severely reduces feed intake and weight. Survivors usually return to normal feed consumption within 60 days but considerably more time is required to recover the weight loss. Iodine-131 can destroy thyroid tissue, which reduces lactation in dairy cattle.
- Radiation has relatively little effect on reproduction, but bone deformities can result if the exposure occurs when limb buds are just starting to form.
- Surviving animals could be used for food under emergency conditions. Muscle meat would be the safest. Milk should be avoided until Iodine-131 levels have declined to a relatively low level.

Effects on Plants

Little is known about the effects of beta radiation on plants. Most of the experimental results have involved gamma radiation. The major findings from one such experiment (5) are as follows:

- Plants are more resistant to gamma radiation than animals (including man) and can survive exposures that would be fatal to human populations. But an exposure which kills only 10 percent of the plants reduces the yield by 50 percent.
- Sensitivity to radiation varies greatly between different plant species (by at least 100-fold) and also varies considerably according to age (by over 50-fold within a single species). A plant near harvest is more resistant than at an earlier stage, and species with small cell nucleus volumes and large numbers of chromosomes are more resistant. Only 1370 rads administered at the seedling stage were required to achieve a 50 percent reduction in barley yield, while 4570 rads were required to achieve the same result in maize. Each crop has its own characteristic period of peak sensitivity.
- Among the major crops, the ranking from most to least sensitive is barley > rye > oats > wheat > maize > groundnuts >sunflower > alfalfa > sorghum > cotton > sugar cane > soybean > rice. Yields for barley were reduced 50 percent by exposure to 500–600 rads; a similar reduction in rice yields required 14 000 rads, about 25 times as much.

IMPACT ON FOOD SUPPLIES

The availability of food after a nuclear war will be affected by a number of factors, apart from the demand for food, as determined by the number of people who survive, and the production of food, as determined by the damage to crops and animals. For example, the expected disruptions of the internal transportation and processing systems would have an important impact on food supplies; merely moving agricultural products from areas of surplus to areas of shortages—either within countries or between countries—would be a problem of immense magnitude. And the reduction in supplies of fertilizers and agricultural chemicals used to produce and protect food would have a substantial impact on production.

The Reference Scenario used for this issue targets a higher proportion of nuclear warheads on oil refining installations than on agricultural chemical plants. As a result, it is assumed in the calculations that fuel supplies are more restricted than supplies of agricultural chemicals. Since the reference scenario indicates ports would be particularly hard hit and some straits would be closed, it is assumed that it would be impossible for the most heavily-targeted areas to either import or export agricultural products or chemicals for some time after the war.

Previous studies (6) have concluded that industrial capacity would suffer proportionately more damage than the human population, and this is assumed to be the case for purposes of this paper. In the most heavily-targeted countries the ability to process agricultural products would be reduced to a small fraction; much of the previous capacity would be destroyed, and there would be little fuel for the plants that escaped destruction.

In Nagasaki, a mother and her child have received a boiled rice ball from emergency workers, but are too apathetic even to eat. Photo: Yamahata Yosuke/from book Hiroshima-Nagasaki.

Global food supplies would also be seriously affected by changes in the atmosphere and in climate. Crutzen and Birks (7) believe the impact on the atmosphere of uncontrollable fires would pose a major threat to agricultural production. In combination with the potential changes in climate due to a nuclear war (8) the effect on food supplies could be substantial, although these considerations are beyond the scope of this assessment.

The impact of all of these factors on food supplies would vary greatly from region to region. So far as food production is concerned, the most heavily-targeted regions, which will be described as "high intensity target regions," are Western Europe, Eastern Europe, the USSR, North America and Japan. The "medium intensity target regions" are the Asian centrally planned economies, South Asia, the Middle East, and several countries in East Asia. The "low intensity target regions" are Latin America (except Cuba), Africa (except South Africa), and Oceania (except Australia).

High Intensity Target Regions

Agricultural productivity in the high intensity target countries is far above the world average. With only one-fourth of the 1985 world population, they will produce about 65 percent of the coarse grain, 60 percent of the wheat, 50 percent of the oilseed, and 40 percent of the cotton. They also produce a disproportionate share of the meat and other animal products.

North America exports massive quantities of animal feeds to the other high intensity target countries, and this trade would come to an abrupt halt. Large quantities of wheat and vegetable oil are also exported from North America and the European Economic Community to the other countries in the high intensity target region, but even larger quantities are exported to countries in the medium and low intensity target regions. All the high intensity target countries import large quantities of tropical products from the Third World, and their inability to import would have important economic consequences for the exporting countries.

Most of the world's fertilizer and agricultural chemicals are produced in the high intensity target countries. They trade large quantities of these products among themselves, but many developing countries also depend upon them for these important agricultural supplies.

North America

In North America, according to the analysis reported by Brown (2), adjusted to include Canada and to account for heavier targeting of cities, the survival rate for humans would be about the same as that for beef cattle and swine, and proportionately, about the same as the damage to the potato and sugar beet crops. Survival rates would be lower for milk cows and wheat, but higher for corn, soybeans and poultry than for humans.

As a result, per capita meat supplies (including poultry) would be slightly higher after the attack than before, even after accounting for the cessation of meat trade. Per capita supplies of dairy products would be lower, egg supplies higher. Sugar supplies would be cut sharply due to the absence of imports, and coffee, tea and cocoa supplies would soon cease to exist. Grain and oilseed supplies would be in excess of the domestic consumption requirement, unless yields were reduced by the lack of fuel and chemicals or because of atmospheric changes. Grain and oilseed stocks would be relatively low, but well above levels in Europe, the USSR or Japan.

About five percent of the 1985 wheat crop would have been harvested by June 11, and a month later 60 percent would have been harvested. Fuel supplies to harvest this wheat and to perform a significant share of the farming operations over the balance of the season would be in the hands of farmers.

North America produces much more wheat, rice, corn, sorghum and oilseed than is needed at home. Most of the grain and oilseed—used for animal feed—is exported to other high intensity target countries. Those exports would stop. By the time spring crops are due to be harvested, fuel supplies in North America would be very tight. Animals and humans would have to be used to harvest crops. Processing soybeans and other raw agricultural products would be impossible.

However foodgrain supplies might be adequate. In 1985, North America is expected to harvest over 100 million tons of wheat and rice; 70 or 75 million tons are scheduled for export. June stocks alone would be more than enough to provide for domestic use for a year, assuming they were not destroyed or contaminated by fallout.

There would be excess supplies of food in rural areas and the people would have to go to them instead of supplies going to the people. The diet would contain a much higher proportion of unprocessed foods.

The USSR

Survival rates for both humans and crops are expected to be slightly higher in the USSR, but the proportions of humans, different species of animals, and crops surviving should be similar to those in North America. However, wheat and barley are the major grains, while sunflower is the major oilseed. These crops are more sensitive to radiation than the major crops produced in the United States (corn, soybeans and wheat). Further, the USSR is a net importer of sugar, other tropical products, meat, wheat, rice, coarse grain and oilseeds. Therefore per capita food supplies would be tighter in the USSR than in North America. Supplies of fuel, fertilizer and other agricultural chemicals would probably be at least as short as in North America, but harvesting the damaged crops may not be as big a problem. A higher proportion of the people work in agriculture and live in rural areas than in North America, so employing "man power" to harvest crops may not be as difficult as it would be in North America or Europe.

Western Europe

Western Europe has high human and animal population densities, and wheat and barley are the major grains. Severe food shortages are expected. Survival rates are likely to be even lower than in North America. Western Europe, especially the European Economic Community, is a net exporter of wheat. But grain stocks would be lower than in North America, and because wheat and barley are more sensitive to radiation the decline in grain production may be proportionately greater than the decline in the human population. Massive quantities of animal feeds are imported by Western Europe, and surviving animals would have to be slaughtered to bring their numbers in line with the feed supply. This would provide a temporary boost in meat supplies, but lead to shortages later. The threat to yields from inadequate inputs of fertilizer and other chemicals and harvest problems would be similar to those in North America. The inability to import tropical products would soon reduce supplies sharply.

Eastern Europe

Eastern Europe also has a relatively high density of humans and animals, so survival rates would be low. The region is a net importer of agricultural products, especially animal feeds, wheat and tropical products. Per capita food supplies would be inadequate. Problems due to inadequate inputs of chemicals and fertilizers and the difficulties in harvesting crops would be similar to those in Western Europe.

Japan

Japan has a very high population density, and relies upon imported agricultural products to a very great degree. Survival rates would be very low, but the rice crop would suffer less than the human population. Even so, supplies would be inadequate, and after the forced slaughter of surviving animals the threat of starvation would be real.

Medium Intensity Target Regions

The medium intensity target countries rely upon plants for food to a much greater degree than the more industrialized nations. Animals are a much less important source of food. In Asia, rice, which is highly resistant to radiation, is the dominant foodgrain. Reliance upon manufactured fertilizer and agricultural chemicals has been increasing rapidly, but by 1985 will still be far lower than in the high intensity target countries. Mechanization of agriculture has also been rising at a rapid pace, and while fuel shortages would be a problem they would not cause the same difficulties as the high intensity target countries would experience. Fewer cities are targeted, and industrial and military targets are much fewer in number. Delayed global fallout levels are relatively high, but still only 25 to 30 percent of the levels expected in Europe or the USSR after one month, and about 40 percent of the levels expected there after ten years. The exceptions are northeast China and North Korea, where fallout accumulations are higher, and Southeast Asia, where they are much lower. The impact on people and agriculture would be much less than in the high intensity target countries.

Asian Centrally Planned Economies

The Asian centrally planned economies have very high population densities, but the intensity of the attack would be much lower. Survival rates would be well above those in Japan or Europe; survival rates for humans and swine would be about the same, but crops should fare better than humans, mainly because rice is the dominant foodgrain. These countries import wheat and agricultural chemicals, mainly fertilizer. But imports are a relatively small percentage of domestic production. Inadequate supplies of manufactured fertilizer and agricultural chemicals would slow progress in agriculture but would not have a major impact on food supplies.

South Asia

South Asia, dominated by India, uses animals primarily as a source of power rather than as a source of food. Rice is the dominant foodgrain but wheat is important in India and Pakistan. However, the 1985 wheat crop would have been harvested by June. Population density is very high and even though only cities with 500 000 people or more are targeted, the percentage surviving is expected to be lower for humans than for food. The need for food imports would therefore decline. The region exports rice and imports a slightly larger quantity of wheat in a normal year. Oilseed meals, sugar and other tropical products are exported, but imports of vegetable oil are very large. A relatively high proportion of the fuel, fertilizer and other agricultural chemicals used in the region is imported. Tight world supplies of vegetable oil and wheat would have an impact on food supplies, but the major shortages are likely to occur in subsequent years, the consequence of inadequate supplies of agricultural inputs. The most serious lack is likely to be the shortage of fuel.

The Middle East

The Middle East relies on imports for a significant share of its food supply. Imports of a large number of agricultural products are climbing at a rapid rate. Agricultural production would be adversely affected by a nuclear war and some of the people would be killed. On balance, the percentage reduction in people may be about the same as the reduction in agricultural production. The inability to obtain food and agricultural inputs from other countries would be the major problem facing the Middle East countries after the initial effects of a nuclear war had been dealt with.

East Asia

The East Asian countries have relatively high population densities, but except for South Korea they are not heavily targeted. Survival rates may be about the same for animals and humans, but crops would suffer somewhat less damage. These countries are net importers of wheat and coarse grain but are becoming self-sufficient in rice, their major foodgrain. They are major exporters of vegetable oils and significant exporters of other tropical products. The East Asian countries would be hurt by the loss of markets for their export products and would have a difficult time obtaining both wheat and the animal feed needed for a rapidly-expanding livestock industry. Restricted availability of agricultural inputs would be a problem, but of relatively moderate proportions.

Low Intensity Target Regions

Survival rates in the low intensity target countries would be very high compared with the high intensity target countries. The primary impact on food supplies would result from the disruption of trade in food and in agricultural inputs.

Latin America

Latin America is now a net importer of wheat and coarse grain, an exporter of meat, oilseeds and oilseed oils and meals, and a major exporter of sugar and other tropical products. Imports of fertilizer exceed domestic production. The inability to obtain fertilizer (and other agricultural chemicals) following a nuclear war would lower yields in subsequent years. However much of the fertilizer is used on tropical crops, and because prices for these crops would be seriously depressed by the inability of the high intensity target countries to import, they would not be fertilized or harvested anyway. Oilseed meals would be in excess supply, but there would be a demand from South Asia and other countries for the region's vegetable oil. Coarse grain and wheat supplies would be inadequate, and changes in diet would have to take place.

Africa

Africa is an important importer of foodgrains and exporter of coffee and cocoa. Export markets would be destroyed and imports would not be available. Existing economic problems would become even more severe. The lack of food aid and agricultural development assistance would also make an already difficult situation much worse. Food shortages would be quite widespread.

Oceania

Oceania is a net exporter of most agricultural products. There would be a strong market for the region's grain, expecially wheat, but sugar and other tropical products, and meat and dairy products are likely to be in excess supply. The agricultural economy would turn even more to grain production, away from animal and tropical agriculture.

CONCLUSIONS

In the immediate aftermath of a nuclear exchange, blast would destroy some food crops, those in cities and at ports. Fire would destroy food stocks, and thousands of hectares of crops would burn. Some crops would be killed from radiation, and surviving crops near targets would yield much less than expected. Lower yields would be the major cause of lower crop production, death the major cause of lower animal product production. The threat to plant yields comes from several directions: initially from radiation, then from atmospheric changes due to uncontrollable fires, inadequate levels of fertilizer, reduced ability to control weeds, insects and diseases, and possibly from changes in climate.

On a global basis, the problem associated with harvesting the crops that survive may be the greatest of all. Global fuel supplies would range from very tight to inadequate, and it may be necessary to use animal and human labor to harvest an abnormally large share of the crops. The transition back from modern agriculture to traditional agriculture would be beyond the experience of surviving farmers in the highly industrialized economies but would be a less difficult transition elsewhere.

The impact of a global nuclear war on food supplies begins with the war and continues for years into the future. The death of millions of people would reduce the need for food but the death of millions of animals would reduce the production of food. Plants would be killed and those that survive would have reduced yields. The destruction of the capacity to produce fertilizers and chemicals to control weeds, plant and animal pests, and insects would seriously affect agricultural production on a global scale. The demolition of the oil refining industry and chaos in oil and gas fields would eliminate energy-intensive agricultural production and processing systems. Fires raging out of control over vast areas and the effect they would have on atmospheric conditions may have both a direct and indirect effect on the yield and production of food. Even changes in climate and world weather patterns are possible. Damage to the food processing systems in high intensity target countries would mean a much smaller range of products for survivors. Disruptions in electrical power and in the communications systems would also disturb the food system. Damage to the internal transportion systems in the heavily-targeted countries and regions would mean excess food and supplies in some areas and severe shortages in others. People would have to move to food instead of food moving to people.

The impact of a global nuclear war would be much more severe in some countries and regions than in others. Closing the straits and demolishing the major ports would stop the flow of food from formerly industrialized countries, and to them from the Third World food exporters. Surviving populations in Japan, South Korea, Europe, and the Middle East would probably face more severe food shortages than those in the United States, Canada or even the USSR. Conditions in Sub-Saharan Africa would deteriorate further, while Oceania would become a more important source of food supplies.

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Economic Consequences: Back to the Dark Ages

BY YVES LAULAN

After the bombs fall there will be no such thing as a world "economy". The millions of dead and wounded in the North would multiply to 1 billion or more in the Third World from starvation and disease brought about by the total collapse of the international system of trade and exchange. The author argues that we would be returning to an economic "dark ages" with emphasis on basic necessities: food, clothing, shelter and medical care.

Conventional warfare is generally limited to the destruction of human resources and wealth. Societal and economic infrastructures remain more or less intact. One of the ironies of history is that war—as we have known it—is often followed by an economic renaissance and renewed prosperity. Germany and Japan make good examples of this: 30 years after the Second World War the "losers" look like the real "winners". This apparent paradox can be explained by the simple fact that in certain circumstances, conventional wars can lead to a better use of resources, full employment, a change in demographics, and the renewal and improvement of plants and equipment.

That disturbing fact can be explained by separating the effect of war on people from its effect on material well-being. So long as the basis of economic activity is not completely destroyed, under certain circumstances a conventional war can be a stimulant to a nation's economy, as World War II was to the economy of the US. Under other circumstances protracted wars involving catastrophic loss of life—like the Thirty Years War in Europe and the current war in Cambodia—can bleed a nation dry, leaving a weakened and exhausted economy.

A nuclear war, however, falls into neither category. The nuclear war outlined in the reference scenario for this issue, given the extensive amount of damage to the Northern Hemisphere, would probably trigger a drastic decline in—if not the near total disappearance of—any form of economic activity except the barter system. We would be returning to the dark ages.

This stark conclusion is based on the following assumptions. A nuclear conflict will pit the largest industrialized countries of Western Europe, Japan and North America against the Soviet Union and Eastern Europe. The combatants would include not only the possessors of the enormous nuclear arsenals, they also represent most of the real economic power in the world. The consequences for the combatants—and thus for the largest economies in the world—can be gauged according to a rather simple formula based on the total number of people killed.

If the loss of human life is limited to less than 10 percent of the total population of any given country the economic consequences can be compared to those of a severe conventional war: after a relatively short period of time, both the economy and even the population recover. A good example is Berlin after World War Two.

However, if 50 percent or more of the populations of the belligerent countries are destroyed, the result could be the end of these particular societies or civilizations as we know them. Since 50 percent is the *minimum* average of deaths for the population centers hit in this scenario, it is safe to predict that this would result in the total disintegration of organized social and economic activities in the Northern Hemisphere. Anthropological and historic evidence have documented time and again that there is a point of no return, beyond which human or animal social groups simply cannot recover, and beyond which their societies cannot long survive.

For purposes of discussion, let us take a medium position, postulating a population loss in the range of 10 to 50 percent—somewhat less than this scenario projects. Even with such an "optimistic" outlook, our society would still go through tremendous convulsions, giving rise to fundamental changes in our patterns of cultural and economic behavior.

First of all it is necessary to recall that humankind's basic needs consist of food, water, clothing and shelter. At a more advanced level, society requires a system of exchanging goods and services, a communications network, medical care, and the possibility of travel. At an even more advanced state, people need higher education, cultural activities, and leisure time. The aim of economic activity is to meet these needs on various levels, by producing goods and services. The excess not needed for immediate consumption can be saved, and those savings can be used to finance further investments intended to maintain or expand the means of production—plants and equipment. Keeping in mind the various elements of the reference scenario, it is possible to sketch out the economic consequences of a global nuclear war. First, investments would completely disappear because all remaining production would be used to meet only the most basic and urgent needs: food, water, shelter, clothing and medical care. Second, money would also disappear. Traditionally money is used as a means of exchange—a sort of yardstick of value—and as a store for the future. In a post nuclear war society (or what is left of it), all modern means of economic exchange would more or less disappear and we would see a rapid demonetarization of the economy characterized by a return to the most elementary form of exchange used by primitive societies—the barter system. And here we are touching a very raw nerve. The international division of labor, along with the commercial and financial means of exchange, has made possible an extraordinary increase of resources and wealth, especially for the industrialized countries, over the past four decades. Commercial and monetary exchange is therefore instrumental for economic growth. Consequently it is most likely that a nuclear world war of the kind envisioned in this issue would result in the total disappearance of organized large and medium scale economic activity at both the national and international levels. This would have dire consequences far beyond the "mere" destruction of physical wealth and human lives, and it is necessary to discuss the impact of a nuclear war both on the means of production and exchange and on economic agents not only in the belligerent countries but in the non-belligerents as well, especially in the Third World.

ECONOMIC CONSEQUENCES FOR THOSE COUNTRIES DIRECTLY INVOLVED

The dead and the wounded

We must realize that aside from immediate and delayed deaths, the casualties in a nuclear attack will also include vast numbers of wounded and incapacitated people. Medical services will be wholly inadequate to deal with the flood of injured, but the attempt must be made, and the attempt will involve massive outlays of scarce resources.

Assuming that about 50 percent of the population is killed outright and another 25 percent are injured or otherwise incapacitated, the remaining 25 percent would be left with the task of attempting some form of recovery. The most immediate result would be a drastic decline in the number of producers and a corresponding rise in the number of consumers—the sick, injured and incapacitated. There would be a fundamental change in the volume and structure of labor as well as of consumption.

In the period immediately following the war, consumption would emphasize medical supplies and services. Under the

force of circumstances these services would become highly specialized—skin grafts for burns, plasma, antibiotics and so on. There would be a change in both quantity and quality of consumption. And certain types of consumption will vanish; most notably leisure activities, travel, education, the performing arts *etc*. Collective needs will overshadow all else, focusing on the procurement of food, water, medicine, basic transportation, and civil protection.

Economic Consequences

In less industrialized societies a nuclear war would have a devastating impact, but would be limited in scope, mainly affecting the area directly involved. However, the more industrialized the society, the more destructive will be the results of nuclear warfare. The vulnerability of a society to a nuclear war is much greater if there is a concentration of people in big cities and a dependence on sophisticated economies based on specialized skills in automation, computers, communications, microelectronics *etc*. Because of the near total destruction of these systems, war in these societies would have a considerable "multiplying" effect.

Indeed, whereas a conventional war can destroy resources but leave relatively intact the communication networks and the basic economic infrastructure, a nuclear war's destruction is immediate, complete and indiscriminate. Its concentration on population and strategic centers would utterly destroy organized economic activity.

The ensuing paralysis would be all the more widespread because destruction would be instantaneous, and would thus impede the rapid substitution of new systems of production and exchange. Under such conditions, it is probably impossible for highly technological societies, like those of Europe and North America, to ever really recover in any meaningful sense of the word. The destruction would be irreversible, at least for a very long period of time.

It is also clear that industrial and agricultural production would collapse, since the survivors will not have adequate substitutes for the machines that previously performed an array of vital economic functions.

In agriculture, for example, horse and tractor power would probably not be available to pull heavy agricultural machinery or to fertilize the land. Fuel would be unavailable and horses mostly unobtainable, if only because many of those that survive would be butchered for their meat. There is also the problem of radioactive fallout, which would render thousands of hectares of arable land useless for food production for some years after the war. As a result, agricultural production will be reduced to primitive levels.

The same applies to firewood. Most modern houses and flats have no fireplaces. If there is no electricity or fuel for cooking and heating and it is impossible to return to the days of the wood stove, how will people be able to cook or keep warm?

In summary, immediately after the conflict our societies would undergo drastic and fundamental changes. Consumption of services would be highly specialized (*eg* medical care) while many activities we now take for granted would simply disappear. There would be an extraordinary drop in the resources available for consumption, which would precipitate an instantaneous drop in the standard of living. It might be like going from the 20th Century back to the dark ages at the snap of a finger. We would be reduced to bare subsistence, and it is clear that this situation would continue for a long time.

CONSEQUENCES OF THE WAR ON COUNTRIES NOT DIRECTLY INVOLVED

Following a nuclear war, the non-combatants, especially those in the Third World, would not suffer as badly as the combatants. But they would still suffer. Developing countries in Asia, Latin America, Africa and the Middle East, with their overflowing populations, dwindling natural resources, lack of arable land and primitive agricultural practices would find themselves in the middle of an overpowering economic and human crisis. Most of these countries cannot now produce enough food to feed their teeming populations; they are heavily dependent on massive imports of food and technology to keep their people fed and their economies running. With the source of vital foodstuffs and technology in ruins, it is likely that the non-belligerents will be more severely affected by a nuclear war than those directly involved. In this case the weapons of death are not nuclear bombs, but widespread starvation, sickness and urban unrest, which would spread over much of the Third World as the total collapse of the international network of trade and exchange became apparent. The 750 million deaths in the Northern Hemisphere would become 1–3 billion in tropical regions and the Southern Hemisphere. Why so many?

Basic Dichotomy Between Population and Resources

Over the past 40 years the world's population has undergone spectacular growth. In 1900 there were only 1.5 billion people in the world. By 1960 this figure doubled to 3 billion and in 1980 it had already jumped to 4.3 billion. It is expected that the global population will be 5.1 billion people by 1990 and 6.1 billion in the year 2000 (1).

Despite the recent downturn in demographic growth, most of that population growth is in developing countries. Africa

The second floor of the machine shop of Mitsubishi Shipbuilding in Nagasaki. The building was [illegible] meters northeast of the hypocenter.

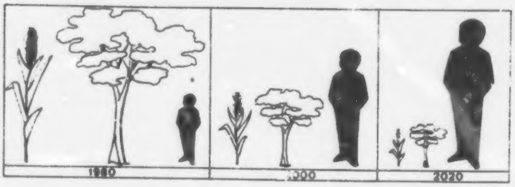

Figure 1. If current rates of land degradation continue, nearly one-third of the world's arable land (symbolized by the stalk of grain) will be destroyed in the next 20 years. Similarly, by the end of this century (at present rates of clearance) the remaining area of unlogged productive tropical forest will be halved. During this period the world population is expected to increase by almost half—from just over 4000 million to just under 6000 million. Source: IUCN/Strategy for World Conservation/Robert Allen, 1980.

and Latin America report annual population growth rates over 2.5 percent; in much of Asia it is 2 percent. But while the population of the less-developed countries has been increasing dramatically, there has been a corresponding drop in agricultural production due to loss of cropland, erosion, desertification *etc.* Population growth is simply outstripping food production (see Figure 1).

The resulting deficit has been balanced by massive imports of foodstuffs. International food and technological aid reached $ 36 billion in 1980—an amount corresponding to the accumulated GNP of 31 developing countries. What happens when the flow of aid ceases altogether?

The world trade in grain is a case in point. Just five countries (US, Canada, France, Argentina and Australia) sold 91 million tons of wheat and rice to deficit countries in Asia (34 million tons), Latin America (9 million tons) Africa (15 million tons), plus Brazil (5 million tons), the USSR (16 million tons), and China (12 million tons) (2). The major exporters—Canada, the US, and France—would be prime targets in a nuclear war.

Yet another important consideration is the international trade in oil, or to be more exact, the international barter system that has evolved: oil to the North in exchange for food and technology for the South. Oil importing countries like the USA, Europe and Japan buy 235 million tons of oil a year from Africa, 866 million tons from the Middle East, 83 million tons from Latin America and 56 million tons from Indonesia (3). In turn, the hard currency from oil sales enables these developing countries to purchase food, agricultural machinery and industrial technology from the West. If the world market for oil should suddenly collapse, as a result of a nuclear war, oil exporting developing countries would find themselves unable to produce the food to feed their burgeoning populations, or the technology to keep their modest industrial infrastructures running. Also many of their investments are in the West. It doesn't take much imagination to foresee the dire consequences for their fragile economies.

GREEN REVOLUTION LARGELY A MYTH FOR THIRD WORLD

Miracle strains of wheat, corn and rice have been developed over the past twenty years, increasing production of these crops by 120–180 percent in the USA, Canada, Europe and Argentina. However the same new varieties produced an increase of only 50 percent in Africa and Asia. And the improved efficiency in agricultural production noted in some Third World countries is highly dependent on continuing purchases of agricultural machinery, fertilizers, pesticides and related technologies from the West. For example, in 1980 the OECD countries sold $ 1 million worth of tractors to Africa, $ 650 million worth to the Middle East and $ 600 million worth to the Far East (4).

Developing countries also imported some $ 2 billion worth of fertilizers—$ 1 billion in Asia alone. What marginal progress has been made in increasing crop yields in tropical or arid countries is dependent upon huge injections of capital, fertilizers and machinery. Take away this economic prop and the Third World's economy will collapse, resulting in widespread starvation and violence.

CONCLUSION: WHAT WILL A POST-NUCLEAR WAR SOCIETY LOOK LIKE?

Economics involves the management of scarce resources, and historically it has been applied to sustain our material needs, and to create powerful bases of economic and military domination. In a post-nuclear war society economics would be devoted to managing very scarce resources indeed. The survivors would find themselves confined to specialized societies with highly planned economies contained inside rather authoritarian regimes. War economics geared to sheer survival, with no regard for growth, would be the dominant configuration. In other words we would be returning to a sort of economic dark ages: inward looking, and locked up in an autocracy that would be primarily agricultural. These societies would most likely be self-supporting and independent of the outside world.

After returning to a certain equilibrium of stagnation, these economies would probably evolve towards an unforeseeable future. We can imagine however, that deep psychological changes would be felt. We would probably see the total breakdown of our present values and motivations. There would be no reason for economic progress as we know it, no will to innovate, invest or invent. Mankind would be moving towards some kind of unprecedented economic pattern. Perhaps we would end up in monastic-like social and economic groupings with the primary emphasis on meditation, introspection and menial labor.

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Science 6 July 1984

Nuclear Winter Attracts Additional Scrutiny

Prodded by Congress, the Pentagon begins to examine the impact of soot on nuclear strategy

Last October, in a widely publicized press conference, a group of leading scientists presented an unusually harrowing portrait of the aftermath of a superpower conflict. At its heart was the novel theory that even a limited nuclear war will generate enough soot and dust to shield a substantial portion of the earth from sunlight, perhaps for months, potentially causing the extinction of numerous plants and animals, including man.

Although this announcement generated little government reaction at the time, it has since given rise to a host of official studies and a promise of additional research funds. It has also galvanized the Congress to demand what may effectively be the first formal environmental impact statement on the consequences of a nuclear holocaust. Similar provisions in the House and Senate versions of the latest defense bill order the Pentagon to produce a comprehensive public report by March 1985 on the latest scientific findings and their implications for nuclear weapons planning, procurement, deployment, targeting, and command, as well as for arms control and civil defense.

Congress approved the requirement after the Natural Resources Defense Council (NRDC), an environmental group in Washington, discovered that the government had by and large ignored the "nuclear winter" scenario depicted by the atmospheric and biological scientists last year. According to the scenario, an exchange of weapons with a total explosive force of 5000 megatons would set massive forest fires and generate voracious firestorms in virtually every major city, creating enough dust and soot to plunge the Northern Hemisphere into a lengthy period of icy darkness, with potentially cataclysmic biological consequences.[*] A climatic model suggested that a smaller exchange of 100 megatons, detonated in large cities, would also lead to a nuclear winter.

Despite the obvious relevance of these scenarios to military planning and civil defense, they were until recently unanticipated by the community of military officials and analysts who set U.S. nuclear strategy. "It really is a new thing," says Charles Zraket, chief operating officer for the MITRE Corporation, one of the Pentagon's principal contractors for nuclear command, control, and communications. "The Pentagon had either been totally unaware of this phenomenon, or it simply failed to consider it during planning. We at MITRE certainly never took it into account; I can say that first-hand." This assessment is corroborated by Richard DeLauer, the Pentagon's top scientist. "We should all perhaps be a little concerned that we did not recognize a little sooner the importance of the smoke to our calculation of nuclear effects," he told Carl Sagan, one of the participants in the nuclear winter study, in a recent letter.

Even after the study was published, few agencies exhibited interest in its implications for their work. "We have not done any work or studies relating to the atmospheric or climatic effects of nuclear war," said an official of the Federal Emergency Management Agency (FEMA), the nation's civil defense headquarters, in a letter to NRDC on 14 March. Similar replies were received from the Arms Control and Disarmament Agency, the Air Force; the Strategic Air Command, and the North American Air Defense Command.

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[*] The theory is explained in detail in an article by R. P. Turco, O. B. Toon, T. P. Ackerman, J. B. Pollack, and Carl Sagan in the 23 December 1983 issue of *Science*, pages 1283–1292.

A notable exception was the U.S. Navy. In an internal memo dated 7 November, Vice Admiral J. A. Lyons, deputy chief of naval operations, wrote that "in the long term, the [results] deserve serious study to see what, if any, changes in U.S. targeting policy are required. In the short term, however, [the] implications are primarily political. I anticipate that the Soviets will make extensive use of these results, especially in Europe, to demonstrate the dangers of the arms race." Lyons proposed that the Navy conduct a careful nuclear targeting study, while simultaneously vigorously rebutting any Soviet propaganda.

Another notable exception was the Department of Energy, which recently committed $3 million for a 2-year study of the nuclear winter phenomenon to be jointly carried out by the weapons laboratories at Livermore and Los Alamos. "At the moment, the calculations are highly simplified, and there are numerous uncertainties," says Michael MacCracken, an atmospheric scientist at Livermore. He notes in particular the need to improve models of climatic change wrought by a nuclear war. The initial nuclear winter presentation, for example, stemmed from a one-dimensional climatic model, which generally neglected local and seasonal atmospheric variations, as well as the moderating impact of the oceans on cooling over land. A subsequent analysis took these factors into account but neglected the effects of dust, the consequences of smoke movement from one locale to another, and the impact of aerosol scattering (*Nature*, 1 March, p. 21). All of the authors acknowledged a pressing need for more realistic models.

A substantial new research effort is also under consideration at the climate office of the National Oceanic and Atmospheric Administration. Alan Hecht, the office's director, is preparing a 5-year research plan that may call for annual expenditures as high as $10 million. In addition to improving climate models, he says, "we want to determine the amount of material that a nuclear explosion sets afire, the amount of smoke generated by the fire, and the proportion lofted high enough to block out sunlight. To do this, we need some large fire experiments—accurate measurements from controlled forest burns, uncontrolled brush fires, or large urban fires."

As a part of NOAA's effort, the Defense Nuclear Agency is planning to increase its funding for fire research from roughly $600,000 to $1 million annually. Prior to the nuclear winter revelation, the agency had essentially overlooked the climatic consequences of massive fires, concentrating instead on how they might be created. This will soon change, according to Marvin Atkins, the agency's deputy director for science and technology. The overall government plan will be submitted to the White House for approval in September.

The Pentagon, which was largely caught unawares by the "nuclear winter" presentation, has been critical of the assumptions in the climatic models developed to date. As MacCracken says, "most of these scenarios are simply not very convincing to people who work in this area." Richard DeLauer, for example, objects to the depiction of scenarios involving the deliberate targeting of cities, which he describes as neither "credible" nor "moral." He and others correctly note that nuclear weapons are today aimed primarily at nuclear weapons and associated military targets. But Sagan replies that many military targets are near large population centers, that some key industries in urban centers are also targeted, and that smaller nuclear powers, such as France, primarily target cities. The present *Force de Frappe* "may itself be sufficient to trigger a global Nuclear Winter," Sagan recently wrote in *Foreign Affairs*.

Another Pentagon argument is that any plausible conflict would exploit less than 5000 to 6500 megatons, the primary estimate used in both the initial nuclear

Soviets Offer Little Help

When Vice Admiral John Lyons, the deputy chief of naval operations, drafted a memo on the "nuclear winter" press conference last October, he noted that Dr. Vladimir Alexandrov of the Soviet Academy of Sciences had presented an extremely advanced climate model, representing "a quantum jump in detail over the work of [Carl] Sagan and his colleagues." It appears that "considerable scientific and computational resources have been devoted to this problem by Soviet academicians," Lyons wrote.

Actually, says Richard Turco, a coauthor of the original "nuclear winter" paper in *Science*, the Alexandrov presentation was "a very weak piece of work, crude and seriously flawed." Turco, an atmospheric scientist with R&D Associates in Marina del Rey, says that the sophisticated Soviet climate model is actually "a primitive rendition of an obsolete U.S. model." Starley Thompson, a scientist at the National Center for Atmospheric Research who coauthored a second major article on nuclear winter, agrees. "Alexandrov's model, which was developed in the United States in the early 1970's, contains a number of defects, and one of his major conclusions is apparently incorrect," Thompson says. In truth, Turco told *Science*, "the Soviets have contributed little to the international 'nuclear winter' study effort thus far, and quite a few people are extremely disappointed."

Turco explains that he and 20 other Western scientists were highly optimistic about potential Soviet contributions when they went to a recent conference in Leningrad sponsored by the International Committee of Scientific Unions. In particular, they hoped to see data on Siberian forest fires, as well as unclassified data on Soviet atmospheric bomb tests, of the type freely available to scientific researchers in the United States. They also hoped to learn the details of a much-discussed Soviet fire experiment. "Instead, we sort of got a rehash of Alexandrov's work. Not only that, but there was no evidence of experimental planning," Turco says.

Turco now suspects either that the Soviets are incapable of contributing meaningful scientific information, or that their goal is to manipulate the issue for potential political gain. How the latter might be accomplished is unclear, as nuclear winter is clearly a global, not a uniquely Western, threat. Recently, the Defense Nuclear Agency decided to take a detailed look at Soviet views of the nuclear winter phenomenon, as part of an ongoing analysis of Soviet research on nuclear effects. But the analysis, to be written by Science Applications Inc., will be classified.—R.J.S.

winter presentation and a forthcoming report by the National Academy of Sciences. Most experts agree that this dispute can only be resolved by experience. A final and clearly legitimate complaint is that all of the models developed thus far assume no geographical overlap between nuclear detonations. In practice, each side would explode at least two and probably more warheads on a given target, just for insurance. This analytical defect may be eliminated in forthcoming studies by Livermore. The entire issue is also scheduled for a thorough review by a newly formed Defense Science Board nuclear winter task force.

Zraket believes that the discovery of nuclear winter has a number of important implications beyond its potential use for propaganda and nuclear targeting revisions. "Assuming that it withstands additional scrutiny, nuclear winter suggests that it is not possible to build a command, control and communications network for a protracted war involving large numbers of nuclear weapons—as some have urged. If you feel—as some do—that a nuclear war can successfully be fought for months, then this should dissuade you. It will reinforce the existing belief that a first strike makes no sense, because it may be suicidal. And it renders the notion of a real civil defense program, which is already in disrepute, even more disreputable."

Zraket, of course, does not have his finger on the nuclear button. The extent to which these views are shared by those who do should become evident in March 1985, with the release of the report that Congress has now ordered.

—R. Jeffrey Smith

NUCLEAR WINTER

A forecast of the climatic and biological effects of nuclear war

by Anne Ehrlich

"Nuclear winter" was recently coined to describe the climatic and biological effects of nuclear war. Drawing on pioneering research in a variety of fields, a growing number of scientists believe that even a "limited" nuclear exchange would trigger a disastrous ecological reaction, and that a full-scale nuclear war might mean the extinction of our species. The seminal study by the TTAPS team, discussed in this Bulletin *supplement, is based on many models, simulations, scenarios and projections; the necessarily hypothetical nature of the findings has opened the scientists to criticism and has provoked debate. But even if further investigation should prove their "doomsday" scenario improbable, the possible consequences of any nuclear war are so horrendous as to demand our most serious attention and research. As Anne Ehrlich points out in her report below, on an issue so vital to the planet, a worst-case analysis is the only prudent approach.*

—The Editors

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NUCLEAR WINTER

by *Anne Ehrlich*

A NEW UNDERSTANDING of the calamitous destructive power of even a "small" nuclear conflict has begun to penetrate the world's consciousness. This awareness stems in large part from the *Conference on the World After Nuclear War*, held in October 1983, at which leading atmospheric scientists and biologists presented their findings in an environmental impact statement. In a packed hotel ballroom bristling with cameras, lights and audio equipment, the scientists described the dire conclusions of their studies and deliberations conducted over the previous 18 months.

Some presentations were highly dramatic—Carl Sagan's brief but graphic "slide show," for example—but mostly they resembled standard conference fare, low-key and unemotional. Yet if anything, the matter-of-fact tone served to underscore the horrors of the picture they were painting of the world after a thermonuclear exchange.

Unlike most scientific conferences, this one offered no controversies or disagreements. Each of the 13 speakers and panelists provided details from his own area of specialization, building on and dovetailing with all the other presentations. Piece by piece, they constructed an image of an unlivable world.

Policy statements were rigorously banned, the speakers all affirming that they would reserve their opinions on policy matters for other occasions. This event was to focus on the stark facts.

Keynote speaker Donald Kennedy, president of Stanford University, described as "most disturbing" the possibility of major climatic consequences from nuclear war "so profound that they could dwarf all of the other long-range effects described so far." While there are still many uncertainties, Kennedy warned that these findings had been carefully reviewed by many respected scientists and were much too important to be ignored by policy planners. "Our most thoughtful projections show," he said, "that a major nuclear exchange will have, among its plausible effects, the greatest biological and physical disruptions of this planet in its last 65 million years."

The possible climatic and biological effects of a nuclear war were long neglected under the assumption that they were trivial compared to the terrible immediate impacts on human populations. The World Health Organization recently estimated that a large-scale exchange might kill 1.1 billion people outright and seriously injure an equal number.[1] Nearly half of the 1984 human population thus would be immediate casualties of a nuclear war, regardless of any environmental effects. But this calamity would be only the beginning.

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Atmospheric consequences.

Carl Sagan presented the TTAPS study (named for coauthors R.P. Turco, O.B. Toon, T.P. Ackerman, J.B. Pollack and C. Sagan) on the atmospheric consequences of a nuclear war. Across a variety of scenarios (see insert and table) the TTAPS simulations produced remarkably consistent results. In a nuclear war involving both urban and military targets, thousands of detonations would inject tremendous quantities of both dust and soot into the atmosphere of the Northern Hemisphere, where the majority of likely targets are located.

The vast fires that would be ignited by attacks on cities were described by panelist Richard Turco of the TTAPS team. World War II firestorms in German cities, he warned, "presage the fierceness of the nuclear fires that might occur in modern cities, except that the nuclear fires . . . would be unprecedented in scale and much more intense, dwarfing any of the World War II conflagrations."

Within one or two weeks, the individual plumes of dust and soot would coalesce in an enormous dark cloud shrouding most of the Northern Hemisphere, particularly the mid-latitude belt encompassing most of the United States, Canada, the Soviet Union, Europe, China and Japan. Beneath the spreading clouds, very little sunlight—in the worst cases, as little as a tenth of one percent of the normal light level, averaged over the hemisphere—could reach the surface (Figure 2). Even relatively limited wars could reduce light intensities by 95 percent or more.

Clouds of dust alone would admit some light because dust particles reflect and scatter much of the light that strikes them, and some would reach the surface. Smoke clouds, by contrast, would absorb most of the solar radiation striking them, very effectively blocking out sunlight as long as they persisted.

With most of the sunlight blocked, temperatures at the surface would plummet tens of degrees, dropping far be-

The Scenarios

Case[a]	Total yield (megatons)	% Yield surface bursts	% Yield urban or industrial targets	Warhead yield range (megatons)	Total number of explosions
A. Baseline exchange	5,000	57	20	0.1-10	10,400
B. 3,000-MT counterforce only	3,000	50	0	1-10	2,250
C. 100-MT cities only	100	0	100	0.1	1,000
D. 10,000-MT maximum exchange	10,000	63	15	0.1-10	16,160
E. 5,000-MT severe counterforce only	5,000	100	0	5-10	700
F. 10,000 MT severe exchange[b]	10,000	63	15	0.1-10	15,160

In these scenarios, attacks are concentrated in the Northern Hemisphere. The 100-megaton cities-only scenario (C) assumes about a third higher smoke emission from urban fires than the other scenarios and no wildfires. "Severe" cases assume a sixfold increase in fine dust lofted per megaton of yield and a greater fraction of soot injected into the stratosphere. (*Source:* TTAPS)

[a] The cases selected from the TTAPS study have been relabeled for this article. The original TTAPS case numbers are: case A = 1, B = 11; C = 14; D = 9; E = 16; F = 17. Case Ax, shown in figure 2, corresponds to TTAPS case 4.

[b] Case F has the same parameters as D; more severe results are posited for F to show the range of possible effects following a maximum exchange.

In their atmospheric models, the TTAPS group analyzed the impacts of some 40 different scenarios on the course of a nuclear war: the numbers, sizes, altitudes, fission yield fractions, and locations of weapons detonated, as well as variations of uncertain physical parameters such as dust and soot particle size distributions, absorption coefficients and so on (see table).

The war scenarios ranged in scale from a relatively modest one involving "only" 1,000 weapons with fission yields totalling 100 megatons (one megaton is equivalent in explosive power to one million tons of TNT) detonated on 1,000 cities, to a very severe one of some 10,000 megatons expended on a variety of targets: cities, major industrial sites, missile silos and other important military installations.

The study also included a 25,000-megaton "future war" scenario, which exceeds in megatonnage the nuclear arsenals of today but will become possible if current plans for expansion are carried out. Two scenarios were given particular attention by TTAPS: a "baseline" case of 5,000 megatons, striking both military and civilian targets; and a 3,000- megaton preemptive strike on silos only, with no retaliation. The biologists focused on the 10,000-megaton "severe" scenario. wishing to apprise decision-makers of a plausible "worst case" outcome.

The kinds of targets and the altitudes of detonations make a difference in the atmospheric effects produced. A high-yield explosion on or near the surface (as most likely would be used against missile silos) tends to hurl vast quantities of very fine dust high into the atmosphere (Figure 1). Because of the stability of temperature and the low water content of the stratosphere, it is subject neither to the rapid vertical mixing nor to the cleansing effects of rain found in the troposphere (lower atmosphere). Very small particles therefore may remain in the stratosphere for long periods—on the order of a year.

While it is uncertain exactly how much dust would be injected into the stratosphere by nuclear detonations, research from nuclear bomb tests indicates a range of roughly 100,000 to 600,000 tons of dust per megaton of yield. Most of the TTAPS scenarios specified production of 330,000 tons of stratosphere dust per megaton exploded in surface bursts and 100,000 tons per megaton in near-surface bursts. The "severe" scenarios were calculated with more adverse, but still plausible, parameters for dust injections.

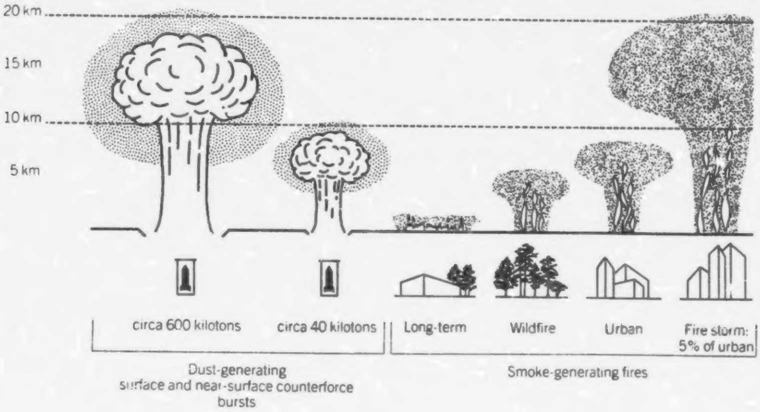
Large numbers of lower-yield air bursts, which probably would be used to inflict maximum damage on cities, would ignite huge fires and deposit enormous quantities of smoke and soot in the troposphere, where they would linger for many weeks. Under normal conditions of air movement the soot particles would gradually settle out of the atmosphere or be removed in precipitation.

The quantities of smoke that would be produced by nuclear detonations are even more uncertain than those of dust. The baseline scenario conservatively assumed partial burning of about 240,000 square kilometers of urban area and total burning of 500,000 square kilometers of forest, brush and grassland area, producing altogether about 225 million tons of smoke particles—roughly equivalent to a year's normal worldwide smoke emissions—within a few days. Their particular composition and their persistence, however, give them a far greater capacity to perturb the atmosphere.

At the Conference, panelist John Holdren of the University of California at Berkeley confirmed the credibility of the TTAPS war scenarios, pointing out their similarity to reference scenarios in other recent studies of the consequences of nuclear war. The baseline case, he noted, "involves the use of about a third of the total [nuclear] inventories, or about a half of the strategic inventories altogether." Even the 10,000-megaton severe case was plausible under very adverse circumstances, such as a small conflict escalating from battlefield weapons to use of the full strategic arsenals.

Figure 1.

Deposit of particles in atmosphere



The graphs which accompany this article were developed by Michael Yanoff, who heads the graphics department of a Chicago financial institution. He has done research, lectured, and led design seminars on the communication of technical information.

low freezing in continental interiors a week or so after the exchange, whatever the season. Extremely cold temperatures would last for many weeks, even months, returning to normal only very slowly (Figure 3). Coastal areas and islands would be spared the extreme cold by the moderating influence of the oceans' vast thermal inertia. But the huge temperature difference between the oceans and the continental interiors would subject coastal areas to months of unremitting violent weather.

How far temperatures fell and how long they remained significantly below normal would depend on the details of the conflicts and the actual values of the uncertain physical parameters. Obviously, the largest numbers of weapons would produce the worst effects. The 10,000-megaton "severe" scenario could plunge average surface continental temperatures in the northern mid-latitudes to around minus 50 degrees centigrade and keep them below freezing for a year or longer.

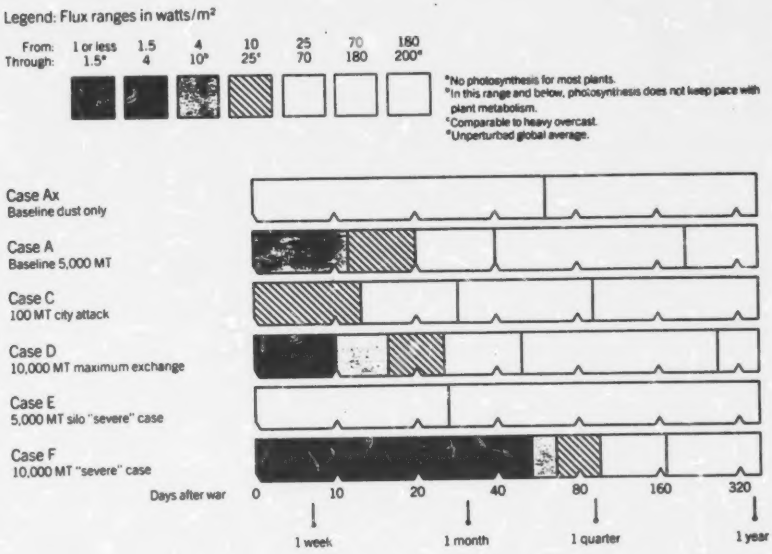
Yet surprisingly harsh and lasting effects could be generated even by relatively modest exchanges. The baseline scenario (5,000 megatons) could drop average continental temperatures in the Northern Hemisphere to about minus 23 degrees centigrade. Shockingly, even 100 megatons detonated on cities alone could produce sufficient smoke to blacken skies and chill continental areas to below minus 20 degrees centigrade, with recovery taking over three months.

Sagan stressed the "robustness" of these findings: "If 0.8 percent of the global strategic arsenals were dropped—100 megatons on 1,000 cities—that would trigger an effect about as bad as the 5,000 megaton case. In other words, these climatic results are very independent of the kind of war we're talking about. And there is a rough threshold of 100 megatons, more or less . . . at which this climate effect can be triggered." He also emphasized that any attack above that "threshold" would be suicidal, regardless of retaliation.[2] As panelist Stephen Schneider noted wryly, an attacker would "win" for only about two weeks.

The extent to which these severe atmospheric effects might spread from the northern mid-latitudes to the tropics or even to the Southern Hemisphere remains uncertain, but TTAPS and other studies using different kinds of models indicate that such propagation is very possible.[3] Schneider offered preliminary results of the National Center for Atmospheric Research (NCAR) study, using a three-dimensional model, which indicated fairly rapid transport of aerosols to the Southern Hemisphere. So did the model used by the Soviet Academy of Sciences, as reported by Soviet

Figure 2.

How dark: Solar energy flux at ground level



Solar energy fluxes at ground level, averaged over the diurnal cycle and the Northern Hemisphere, from selected TTAPS scenarios. (Source: TTAPS)

scientist Vladimir Aleksandrov. If they are right, the atmospheric effects—the cold and the darkness—of a nuclear war would engulf the entire globe.

In most respects, both the NCAR and Soviet studies confirmed the TTAPS results. "Everything we've seen so far," Schneider said, "suggests that, although the details do vary . . . the basic picture [is] very hard to get rid of." Turco and other speakers nevertheless stressed the continued uncertainty on details of the atmospheric effects despite the general agreement.

A point emphasized in the Soviet study was that normal precipitation might be suppressed by the dust-laden, warmed atmosphere following a nuclear conflict. The Soviets also found that, as the solar-heated soot clouds cleared, surface temperatures could become much *warmer* than normal—as much as 25–35 degrees centigrade above average—in continental interiors. (But this effect may well be an artifact of the model, in which soot clouds dissipate suddenly rather than gradually over months.)

BEYOND the "nuclear winter," the TTAPS study found that massive burning of synthetic materials in urban and industrial areas would release—besides smoke—a deadly mix of toxic fumes (labeled "pyrotoxins" by TTAPS) such as carbon monoxide, oxides of nitrogen, ozone, cyanides, dioxins and furans, to blanket much of the Northern Hemisphere for months.

TTAPS also confirmed earlier findings that a nuclear war could cause destruction of stratospheric ozone, allowing penetration of radiation in the ultraviolet-B range. While the smoke and dust clouds persisted, they would absorb most of the ultraviolet-B, but the ozone shield would be reestablished more slowly. Thus, clearing skies would expose Earth's surface to the damaging radiation for some years.

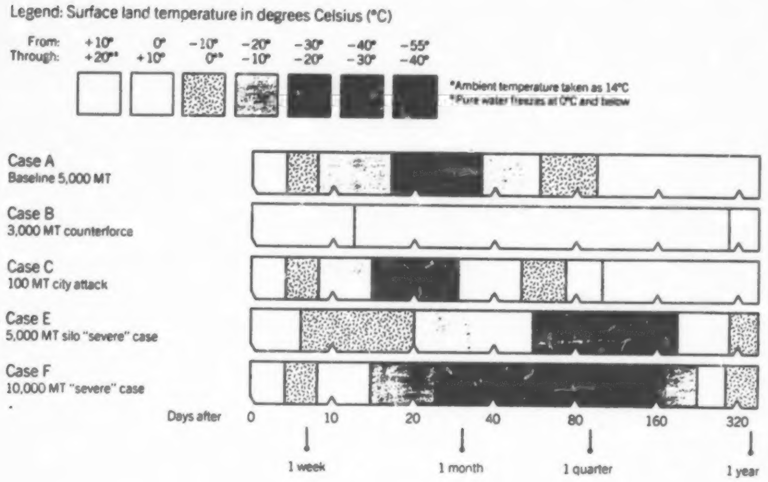
The baseline scenario projects a reduction of ozone concentrations of up to 30 percent, averaged over the Northern Hemisphere. This would produce ultraviolet-B exposures at the surface roughly twice the normal level after cloud dissipation. Higher megatonnage wars would produce relatively greater depletion of the ozone shield—twice as much for a 10-megaton exchange, for instance.

In addition, the TTAPS report included new predictions on the distribution and, especially, the timing of radioactive fallout. Previous studies, based on high-yield test explosions, had focused on immediate and long-term fallout. But they had neglected medium-term fallout, that occurring between a few days and a few months after a nuclear exchange. Virtually everyone exposed to immediate lethal doses of radiation from fireballs would be killed by blast and heat. Prompt fallout (within a day or two) also would be largely confined to target areas. Earlier intermediate and long-term radiation estimates rested on the generally unspoken assumption that most radioactive debris would be injected into the stratosphere where it would remain for one to two years. By then, most of the radioactive elements, which are fairly short-lived, would have decayed to relatively harmless levels.

Calculations by the TTAPS team, however, indicated that the medium-term component, mainly from rapid washout

Figure 3.

How cold: Temperature at ground level



Temperature trends for Northern Hemisphere interior land areas, averaged over all latitudes and seasons, for selected TTAPS scenarios. "Counterforce only" scenarios involve only military targets, no cities, hence no smoke is produced. The effects in such scenarios are all from stratospheric dust. (Source: Carl Sagan)

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and fallout of radioactive debris deposited in the troposphere by low-altitude and ground-level bursts, might be substantial. Thus, for a conflict of any given size, the average exposure to survivors far from targets might be increased by an order of magnitude over earlier estimates. Panelist John Holdren compared these new findings to those of another recent study conducted at the Lawrence Livermore Laboratory. Both studies had revealed the likelihood of considerable intermediate-term fallout, which would, as he put it, "contribute rather nastily to the total dose."

For the baseline case, the average medium-term, whole-body, external dose of gamma emissions to unsheltered people in the Northern Hemisphere could be about 20 rad. The average dose in the northern mid-latitudes might be 50 rad, and exposure to local "hot spots" and internal doses from food could easily add another 50 rad. A great many individuals, especially downwind of major targets, would receive far greater than average doses.

Average doses of 100 rad or so imply serious problems for an exposed population, especially in the probable absence of even minimal medical care and with simultaneous exposure to numerous other severe stresses. With adequate medical care, the whole-body radiation dose that would kill half of the exposed healthy adults is thought to be about 350 to 500 rad if received in 48 hours or less. Under adverse conditions, the lethal dose might be much lower. If so, at least half of the surviving populations of combatant nations in a nuclear war of even moderate size could be exposed to life-threatening doses of radioactivity in the aftermath, and nearly everyone could suffer some resulting illness.

A nuclear conflict involving greater megatonnage would produce proportionately larger radiation doses. The 10,000-megaton severe scenario in the TTAPS study might result in exposures of about 500 rad over 30 percent of the Northern Hemisphere land areas, killing at least a half-billion people.

QUESTIONS from the audience dealt with several other points:

- Why the climatic consequences had not been discovered before was unanswerable. The basic physics and chemistry had been available for 20 years, and governments had a responsibility to study them.
- Whether massive disruption of the hydrological cycle would cause torrential rains and heavy erosion was difficult to predict. In the absence of sunlight, evaporation would be sharply reduced, thus possibly diminishing the moisture content of the atmosphere and suppressing precipitation.
- Could these discoveries be made public in the Soviet Union? Golitsyn replied that some aspects of his work had already been published in the proceedings of the Soviet Academy of Sciences.

Biological consequences.

"The environment that will confront most human beings and other organisms will be so altered and so malign that extreme and widespread damage to living systems is inevitable," declared Paul Ehrlich, who presented the biologists' consensus on the biological implications of the TTAPS discoveries.

The reduction of sunlight by more than 95 percent for several weeks would represent a severe assault on green plants—the foundation of all significant ecosystems. Virtually all animals, including human beings, are directly or indirectly dependent on the energy green plants capture from sunlight in the process of photosynthesis.

Panelist Joseph Berry, a plant ecologist at the Carnegie Institute, reminded the audience that photosynthesis is the "major . . . energy input in the biosphere . . . the driving force for the operation of natural and agricultural ecosystems." In most plants, photosynthetic activity is proportional to the amount of light they receive, and 15 percent or more of the energy fixed is needed to maintain life processes. If light falls below that point, plants begin to "consume themselves," and animals also consume them. A severe loss of light thus means loss of biomass.

Under the smoke-shrouded skies of a nuclear winter, for several weeks light intensities would be too low to permit growth in most plants. The 10,000-megaton "severe" case could turn midday into the equivalent of a moonlit night for many weeks—too dark for any photosynthesis at all—and complete recovery to pre-war light levels would take more than a year.

The darkness, drastic in itself, would be accompanied by plummeting continental temperatures. Growing plants are as sensitive to temperatures as they are to light intensities; even quite small changes can make significant differences. A reduction in average temperatures of one degree centigrade at critical times can reduce corn crop yields by as much as 10 percent, for example.

Temperatures far below freezing during the growing season would annihilate annual plants, including most crops, and kill or severely damage even the hardiest perennials. Even normally cold-tolerant species, such as winter wheat and deciduous trees, need time to acclimate to winter cold. More sensitive plants, including many important crops, could be seriously harmed by low temperatures that only *approached* freezing during the growing season.

Moreover, the effects of cold and darkness would interact synergistically, each intensifying the other. Cold-damaged plants need abundant sunlight to repair the damage, and the rate of photosynthesis is retarded by low temperatures. Plants in the tropics and subtropics are particularly vulnerable; if the climatic effects spread southward, both crops and natural vegetation in those regions would be devastated.

EXTREME COLD and darkness would also have disastrous impacts on animals. In seasons that are normally warm, animals would be especially vulnerable to sub-freezing temperatures. Hibernating animals need a full summer's buildup of fat reserves to last through a normal winter, let alone a protracted, super-cold nuclear winter. Herbivores

Figure 4.

Timing and magnitude of effects of baseline nuclear war

	Population at risk					Time after nuclear war									
Effect	US-Soviet Union	Northern Hemisphere	Southern Hemisphere	Potential deaths, globally	Total casualties	1 hr	1 day	1 wk	1 mo	3 mo	6 mo	1 yr	2 yr	5 yr	10 yr
Blast	H	M	L	H	M-H										
Thermal radiation	M	M	L	M	M-H										
Prompt ionizing radiation	L	L	L	H	L-M										
Fires	M	M	L	M	M										
Toxic gases	H	M	L	L	L										
Darkness	H	H	M	L	L										
Cold	H	H	H	H	M-H										
Freezing of water supplies	H	H	M	M	M										
Fallout of ionizing radiation	H	H	L-M	M	M-H										
Food shortages	H	H	H	H	H										
Medical system collapse	H	H	M	M	M										
Contagious diseases	M	M	L	H	M										
Epidemics & pandemics	H	H	M	M	M										
Psychiatric disorders	H	H	L	L	L-M										
Increased surface ultraviolet light	H	H	M	L	L										
Synergisms	?	?	?	?	?					?					

H = high, M = medium, L = low. For global deaths, L = less than 1 million, M = 1 million to 1 billion, H = more than 1 billion. (Source: Mark Harwell, Carl Sagan)

would starve and their deaths would deprive carnivores of food. Lacking human care, domestic animals would be in similarly desperate straits; most would soon perish.

Thirst would be another problem. Panelist John Harte, of the University of California, has calculated that ice, one to two meters thick, would form on inland surface waters. If precipitation were reduced as well, people and farm animals would die of thirst – one more malign synergism. "It's interesting how synergies seem to work with you when things are going well," he remarked, "and they turn against you when you and nature are down."

Aquatic ecosystems, sometimes thought to be a potential source of food for human survivors of a nuclear war, would also suffer. Marine phytoplankton, the photosynthesizing base of marine ecosystems, are highly susceptible to prolonged darkness; their disappearance would quickly lead to starvation of animals higher in marine food chains. These systems moreover would be inundated by runoff from shore of toxic compounds released from ruptured storage and industrial facilities and of silt from denuded, burned-over lands. And the violent storms likely to prevail along coasts would make harvesting any surviving sea life difficult if not impossible.

Ionizing radiation would be an additional threat to all forms of life. Most birds and mammals are nearly as sensitive to radiation as are human beings. Sensitivity varies substantially among plants but is higher among conifers and some crops. Fallout could kill or damage millions of trees, rendering forests susceptible to wildfires, and adding to the atmospheric soot burden. Radiation also inhibits photosynthesis, an effect exacerbated by low temperatures and lack of light.

George Woodwell, moderator of the biological panel, reported that his early experiments with radiation effects on forests had indicated biotic impoverishment and quicker recovery of species with short life cycles and high reproductive potential, namely, pests. He emphasized the central importance of forests in the biosphere; their destruction would cause an enormous acceleration of extinctions. A postwar world would contain few forests; they could quickly be destroyed, but very slowly replaced.

When skies cleared, ultraviolet-B radiation, admitted at twice or more pre-war levels, could significantly affect virtually all organisms. It can reduce productivity in plants, especially under low light conditions, and might severely disrupt oceanic food webs. In mammals, ultraviolet-B can suppress immune systems, as can ionizing radiation, and cause visual damage and blindness.

Persistent darkness, below freezing temperatures, ionizing radiation, toxic air pollution, widespread fires and completely unpredictable, possibly extreme weather are each capable of causing disasters. The combined assaults of *all*

Soviet participation

A highlight of the events was the "Moscow Link," in which a dialogue between Soviet and American scientists was shown via closed-circuit satellite video on large screens to audiences in both Washington and Moscow immediately after the Conference. Representing the Americans were Thomas Malone, Paul Ehrlich, Walter Orr Roberts and Carl Sagan; the Soviet spokesmen were astronomer Evgeny Velikhov (vice president of the Soviet Academy of Sciences), meteorologist Yuri Izrael, geneticist Aleksander Baev and physician Nikolai Bochkov. Unlike the Conference proceedings, this exchange ventured into the policy arena.

Sagan briefly outlined the findings of the TTAPS study, emphasizing the consistency of atmospheric consequences even in "rather modest" scenarios, such as the 3,000–megaton counterforce war which could produce effects severe enough "to wipe out the wheat- and corn-producing areas of the United States, Canada, and the Soviet Union." The resultant "set of simultaneous assaults on the biosphere of unprecedented magnitude . . . must follow a nuclear war even of relatively small yield."

Sagan declared that "the combined arsenals of the United States and the Soviet Union [are] many times . . . above the threshold [that could produce catastrophic climatic effects]. . . . Since the early 1950s, the leaders of both nations have been making decisions on world affairs in ignorance of the possible, very dire climatic consequences of the use of nuclear weapons."

Paul Ehrlich summarized the unanimous conclusions of a large group of distinguished biologists on the implications of the TTAPS results for biological systems. With simultaneous exposure to the cold, darkness, fallout, toxic air pollution and increased ultraviolet-B, "the basis of the planet's productivity, at least in the Northern Hemisphere, [would have] been hit by a series of assaults, *any one of which* would be extraordinarily damaging."

A large-scale war would halt agricultural productivity for at least a year, destroy most stored food supplies and freeze inland water sources. "In general, [biologists] can see nothing but a collapse of the life-support systems, at least in the temperate zone of the Northern Hemisphere—a situation in which any sort of survival of civilization . . . would be difficult or almost certainly impossible. . . . The biological results were obvious and very robust for the whole range of scenarios."

While the extent to which the climatic effects would spread to the Southern Hemisphere was uncertain, Ehrlich said, they were virtually certain to reach the northern tropics, resulting in destruction of some tropical forests—the greatest reservoir of organic diversity on the planet. Survivors in the Southern Hemisphere would be "faced with a situation that would be entirely unprecedented [and] extremely malign."

The Soviet scientists presented their findings, which generally confirmed those of TTAPS, with a few, relatively minor, differences. Yuri Izrael noted that human industrial activity "has already led to a number of ecological and global problems arising. It is quite obvious that, in the case of a nuclear war, the biosphere will be even more affected by many orders of magnitude and [this] will lead to catastrophic results for humanity and for the biosphere as a whole."

Izrael related that the Soviets had found that only about one percent of the dust and soot lofted into the atmosphere by a nuclear exchange would persist more than two weeks, but even this could produce disastrously low surface temperatures. The Soviets furthermore projected a possible later rise in surface temperatures because of the absorption of outgoing infrared radiation by the aerosols and by "gaseous admixtures"—ethane, methane and so on—including a doubling of carbon dioxide concentrations. These pollutants could increase surface temperatures by about three or four degrees centigrade, a "hothouse effect" that would cause the "practical destruction of agricultural activity." The combined synergistic effects would affect not only the "warring factions" but others as well. There would be no victors: "In the final analysis, all sides suffer fatally."

Aleksander Baev asserted that nuclear war was immoral and the loss of human lives—as many as half of the entire human population—would be unacceptable. For the survivors, "their continued existence will be difficult and problematic." At best, peoof these, occurring simultaneously or in rapid succession over weeks or months, followed by more months of exposure to enhanced ultraviolet-B radiation, would have catastrophic, often synergistically amplified, effects on both natural and agricultural ecosystems. (See Figure 4 for the relative timing of individual effects.)

Joseph Berry noted ominously that, over geologic time, global photosynthetic productivity has been remarkably constant, varying only about 5 percent. The devastation of plant life caused by a nuclear winter could cut photosynthesis in the Northern Hemisphere by 80 to 90 percent in the first year. Because of the sharp reduction in biomass and the retarding effects of ultraviolet-B on growth, restoration of productivity to normal levels would be very slow.

Uncountable populations of plants and animals throughout the Northern Hemisphere would be obliterated; their disappearances would reverberate through ecosystems as the loss of one population led to the eradication of others dependent on it. In subtropical and tropical regions, where species diversity is far richer, but where most organisms are less able to tolerate loss of light and warmth, the cascade of extinctions could reach proportions unequalled since the dinosaurs disappeared at the end of the Cretaceous period. Even if climatic conditions returned essentially to normal within a year or two, ravaged ecosystems would require far longer to recover a semblance of their former productivity and stability—possibly millenia.

THE VITAL SERVICES that natural ecosystems provide in support of humanity depend on their productivity and stability.[4] Those services include maintenance of the quality and composition of the atmosphere, moderation of climate and weather, regulation of the hydrological cycle, cycling of nutrients (including those needed in agriculture), disposal of wastes, replenishment of soils, pollination of

ple "will survive only as small islands in a lifeless and hostile environment." Nikolai Bochkov stated that the study of the consequences of nuclear war was a most important task for all biologists: "We [Soviets] are optimists," he said, "and hope that humanity will give up any thought of using nuclear weapons." The Soviet study had shown a massive breakdown of normal atmospheric circulation patterns, following which "all the dirt from the north will wander" to the Southern Hemisphere and "on the globe, there will be no place to be found that will not experience all the consequences of such a nuclear conflict."

From the Moscow audience, K. Kontratyev, an atmospheric physicist at the University of Leningrad, spoke up on one more atmospheric effect: extrapolations from nuclear tests in 1961–1962 indicated that stratospheric additions of nitrogen dioxide would strongly absorb solar radiation, producing a surface cooling of 9.5 degrees centigrade in a full-scale war. Gaseous nitrogen dioxide would persist far longer in the stratosphere than would dust particles, thus inflicting on the Southern Hemisphere the same dire consequences, he claimed. Other scientists, however, were dubious about this possibility.

As a scientist, Sagan was gratified that Soviet and U.S. scientists had independently reached such similar conclusions, but noted lingering uncertainties about scenarios chosen, amounts of soot and dust lofted, particle agglomeration, residence times, changes in atmospheric circulation and radiation doses. He asked: "Do our Soviet colleagues think it possible that they might supply data on the particle size distribution function of debris from the Soviet nuclear tests before the 1963 Limited Test Ban Treaty? And information on particle sizes and absorption coefficients from large fires in the Soviet Union? And also will they eventually give us the range of nuclear war scenarios that they consider likely?"

After a tense pause, Izrael responded. "Our dialog . . . should be continued, probably during meetings of scientists at conferences . . . I also have many questions for my American colleagues on the initial data that they used in constructing their models." Other Soviet scientists expressed agreement on the importance of further cooperation and collaboration.

Ehrlich thanked Bochkov for bringing up the matter of long-term genetic effects from radiation. Increased cancers and birth defects, compounded by the effects of inbreeding, could burden future generations. Genetic damage would also be inflicted on natural ecosystems by both radioactive fallout and ultraviolet-B radiation. Because of the unknown extent of this damage, in addition to all the other assaults which would create an entirely new set of selection pressures, it was impossible to predict how these systems would recover. Surviving groups of people would be facing a totally new environment bereft of any useful cultural resources to help them cope with it.

G.K. Skryabin, General Science Secretary of the Soviet Academy, spoke of his "feeling . . . about the possible tragedy that cannot but worry and bring concern to any normal human being." But he also commented that "our American colleagues and Russian scientists . . . here are unified in their view that there should be no nuclear war, that this means disaster and death for mankind. The authority of scientists is very great . . . we should all try to bring our influence to bear in order to bring about an end to the arms race so there will never be a nuclear war."

Ehrlich responded: "All of us over here share that wish most devoutly. . . . Not only is the East/West confrontation threatening to the Soviet Union and the United States and their direct allies, but it is also threatening every human being on the planet *at least* with grave injury and, probably for almost everyone, death. This has got to form the background for the policymakers of the world." Thomas Malone added that in future years the Conference might be viewed as a "turning point in the affairs of man."

"The only conclusion possible here," Velikhov said, "is that nuclear devices are not and cannot be a weapon of war . . . or a tool of politics. . . . Nuclear superiority is a delusion. . . . Nuclear arms are not muscles of [the] modern state; they are a cancerous growth which threatens the very state. . . . Either we will destroy the cancerous growth or [it] will destroy us."

Finally, Walter Orr Roberts expressed the hope that the scientists all could collaborate in efforts "to reduce the uncertainties. . . . But we already know enough to realize that it's imperative, in the name of all humanity, to accelerate the search for world security in the policy domain, as well as in the scientific domain. And, as citizens of our own nation-states and as residents of this fragile spaceship Earth, we must invent and enact new policies that covenant a stable future for that planet and for all of its people."

crops, and a vast "genetic library" from which society has already drawn the very basis of civilization.

The loss or severe disruption of those services would inevitably follow the massive destruction of natural ecosystems by a nuclear war—just when human populations needed them most. John Harte vividly explained: "All of us on Earth are dependent on the ecosystems surrounding us as an intensive care patient is on I-V bottles and life-supporting medical equipment. Waging nuclear war would be akin to throwing a stick of dynamite into an intensive care ward, rupturing the vital links that ensure survival." Thomas Eisner of Cornell University noted the difficulty of preparing a detailed environmental impact statement for nuclear war, because biological systems are extremely complicated and still poorly understood; the impacts would be all-encompassing; and recovery from such a host of massive assaults would be slow, compounded by synergisms.

Like natural ecosystems, agricultural and other managed systems would be devastated. Any farmers still able to farm would be cut off from supplies of seeds, fertilizer, pesticides, and fuel. Starving animals, domestic or wild, might invade fields in search of food, and pests would proliferate unchecked. At least in the northern mid-latitudes, agricultural production in the first year after a nuclear war of significant size would be essentially nil, and it would be problematic for subsequent years. Modern agriculture as practiced today in developed countries would probably never be seen again. Panelist Mark Harwell of Cornell University noted that human survivors would therefore be dependent on natural ecosystems for sustenance, an additional

About the Conference

Conference participants watch monitor screens with images beamed via satellite to Moscow.

The Conference on the World after Nuclear War, born a few years ago, resulted from a confluence of interests among environmentalists, some scientists and a handful of foundation executives, who realized that existing studies of the environmental consequences of nuclear war were appallingly deficient.

Although immediate impacts on human populations from blast, heat, fires and radiation were well known, the only long-term effect that had received much attention before the early 1970s was radioactive fallout.[1] Then came the discovery that large quantities of oxides of nitrogen generated by high-yield fireballs could rip gigantic holes in the protective ozone shield in the upper atmosphere, allowing greatly increased amounts of light in the ultraviolet-B range to reach Earth's surface.[2]

The possibility that nuclear war could have drastic effects on climate attracted serious attention for the first time in 1982. The first quantitative study of the impact on Earth's atmosphere from smoke generated by fires in a nuclear war appeared in an article in *Ambio* by Paul J. Crutzen of the Max Planck Institute in Mainz and John W. Birks of the University of Colorado.[3] Crutzen, a panelist at the Conference, related that he and Birks had focused mainly on the destruction of ozone by oxides of nitrogen in the stratosphere; but they also looked into the quantities of smoke that would be produced by fires, and their calculations indicated that sunlight would be substantially blocked from reaching the surface for many weeks in the Northern Hemisphere.

Cornell astronomer Carl Sagan, whose interest had been piqued a decade earlier by observations of a giant dust-storm on Mars, saw the implications of the article by Crutzen and Birks. Sagan and colleagues Richard P. Turco, of R & D Associates, Marina del Rey, California, and O. Brian Toon, Thomas P. Ackerman and James B. Pollack of NASA further investigated the impacts of the dust and smoke that would be injected into the atmosphere by a large-scale nuclear war, using physical models of Earth's atmospheric circulation. They summarized their findings in early 1983 in a 120-page manuscript entitled "Global Atmospheric Consequences of Nuclear War." (The group's surname initials formed the acronym which led to the study being dubbed "the TTAPS Report.")

For years, Stanford biologist Paul Ehrlich had been writing and speaking about environmental consequences of nuclear war, which previous studies had largely neglected. In 1982, when he circulated for review a manuscript on that subject to other interested ecologists and evolutionists, two of them suggested he send it to Carl Sagan.[4]

Around that time, a group of environmentalists and foundation people, who realized that nuclear war posed the ultimate, though generally unrecognized, environmental threat, were planning a conference on the "Long-Term Worldwide Biological Consequences of Nuclear War" to be held in late 1983. The three groups, on learning about each others' efforts, decided to collaborate in developing and confirming the new information on

Thomas Malone (left) and Walter Orr Roberts.

pressure that would surely delay the recovery of those systems.

Impacts on the human population.

Human survivors of a large-scale nuclear conflict would face a dark, swiftly chilling, radioactive, smoggy world in which most of the social services we take for granted—medical care, food and water distribution systems, centralized heat and power supplies, communications and so on—had completely broken down. Cities and industries would be in ruins; surface water supplies would quickly run out; and no assistance from the outside could be expected.

The few healthy survivors would be burdened by masses of corpses and seriously injured friends, neighbors and relatives needing care. In the absence of functioning sanitation systems and medical care, diseases would flourish in a population weakened by exposure, radiation and malnutrition. The psychological burdens can be only dimly imagined.

Apart from the difficulties of keeping warm, finding unfrozen water, and avoiding radiation exposure and the choking smog, food would be the most urgent need. The war undoubtedly would have destroyed much food in storage as well as crops in the fields. Worldwide food production rarely is abundant enough to provide carry-over stocks that would last for more than two months under normal consumption patterns.

Only grains are stored in large quantity, usually far from population centers. Thus any grain that escaped destruction would be largely inaccessible. Without agricultural produc-

Paul Ehrlich (left) and Carl Sagan.

climatic effects and to present it to the public at the conference. Ecologist George Woodwell of the Marine Biological Lab at Woods Hole, Massachusetts became chairman; Chaplin Barnes of the Audubon Society was executive director. Sponsorship by a consortium of environmental, scientific, educational and other public interest organizations was obtained, as well as financial support from foundations and individuals.

In April 1983, two preliminary meetings in Cambridge, Massachusetts were attended by over 70 distinguished physical scientists and biologists. The TTAPS study was presented first to the physical scientists, who had numerous questions about details but very little quarrel with the findings. Several of the scientists went home resolved to try the scenarios on *their* atmospheric models—among them Stephen Schneider of the National Center for Atmospheric Research and Vladimir V. Aleksandrov of the Soviet Academy of Sciences Computer Center, the only Soviet scientist able to attend the meeting.

The biologists then examined the consensus results of the physicists. They too had many questions about details of the atmospheric findings but essentially no disagreement on the impacts of anything resembling the TTAPS effects on biological systems, agriculture or human life.

During the spring and summer, the TTAPS paper was refined in the light of reviewers' comments while 20 of the biologists prepared a manuscript on the long-term biological consequences of the atmospheric changes forecast by TTAPS.[7] Both papers were submitted to *Science*, to be published soon after the meeting which now bore a less cumbersome name, "The Conference on the World after Nuclear War."[5] Meanwhile, preliminary results had begun to emerge from other atmospheric studies being conducted at the National Center for Atmospheric Research, the Soviet Academy of Sciences and Lawrence Livermore Laboratory.[6] These findings were also incorporated into the Conference presentations.

The 700 remarkably diverse participants who attended included dozens of scientists as well as people from foundations; from the 31 sponsoring organizations and other public interest groups; from religious, educational and medical institutions; from the press, the U.S. government and several other governments; and from businesses as disparate as Lockheed and Random House.

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2. National Academy of Sciences, *Long-Term Worldwide Effects of Multiple Nuclear-Weapons Detonations* (Washington, D.C.: 1975); Office of Technology Assessment, *The Effects of Nuclear War*, (Washington, D.C.: 1979).
3. *Ambio*, 11, nos., 2–3 (1982), pp. 114–25.
4. Published as a chapter in Jennifer Leaning and Langley Keyes, eds., *The Counterfeit Ark* (Cambridge, Massachusetts: Ballinger, 1983).
5. R.P. Turco, O.B. Toon, T.P. Ackerman, J.B. Pollack and C. Sagan (TTAPS), "Nuclear Winter: Global Consequences of Multiple Nuclear Explosions," *Science*, 222 (Dec. 23, 1983), pp. 1,283–92; P.R. Ehrlich and others, "Long-Term Biological Consequences of Nuclear War," *Science*, 222 (Dec. 23, 1983), pp. 1,293–1,300.
6. C. Covey, S.H. Schneider and S.L. Thompson, "Global Atmospheric Effects of Massive Smoke Injection from a Nuclear War: Results from General Circulation Model Simulations," *Nature* (submitted); V.V. Aleksandrov and G.L. Stenchikov, "On the Modelling of the Climatic Consequences of the Nuclear War," USSR Academy of Sciences, Computing Center, The Proceeding on Applied Mathematics (Moscow: 1983); J. Knox, *Report UCRL-89907*, Lawrence Livermore Laboratory (1983).

tion, even a heavily decimated population would face severe and continuing food shortages in a short time—although they would be alleviated somewhat in developed countries by the disappearance of livestock as competitors for grains.

Many European countries, Japan, and often the Soviet Union are deeply dependent on food imported mainly from North America, as are numerous developing nations. Shipments of food and other commodities obviously would halt immediately, throwing many regions into almost instant famine. In the sub-tropics and tropics, people might turn in desperation to the remaining forest areas, try to convert them to subsistence agriculture, and thereby greatly accelerate the already disastrous current rate of tropical deforestation, compounding the destruction caused by the atmospheric disturbances.

In the northern target regions, it is unlikely that more than a tiny fraction of the original population could survive the first few months after a nuclear war of appreciable scale. Even though atmospheric conditions might return more or less to normal in a few years, other aspects of the environment would be altered beyond recognition. Ecosystems would recover slowly, with entirely new structures, impoverished species compositions and a reduced capacity to support human life. Local climates would probably be novel and unpredictable. Pre-war cultural adaptations would be useless in such a changed, hostile, unstable world.

THE FAMILIAR complex technological civilization that supports us doubtless would be shattered beyond repair Once destroyed, that technological superstructure could not easily be rebuilt, because the resources used to build it the first time would no longer be at hand.

Ehrlich concluded: "If there is a full-scale nuclear war, odds are you can kiss the Northern Hemisphere goodbye. . . . Odds are also that the effects will be catastrophic in the Southern Hemisphere." If so, he declared, the scientists had decided for the first time that they "could not preclude the extinction of *Homo sapiens*." Small isolated human groups might persist for several generations in a strange, inhospitable environment in the Southern Hemisphere, their adaptive capacities sapped by inbreeding and a burden of genetic defects from the postwar exposure to ionizing radiation and increased ultraviolet-B—a classic recipe for extinction.

Where can we go from here?

Clearly, society can never again view the prospect of nuclear war as it did before. Any possibility of meaningful survival has been removed, and no place on Earth is safe from the nuclear winter. But these newly discovered consequences of nuclear war are so all-encompassing and so devastating that most people need some time to absorb the implications. The question, therefore, is how soon a realization of the significance of these findings can be translated into a concerted, worldwide effort to reduce international tensions.

Critics of the conference and its conclusions have contended that release of the findings was premature and would frighten an already frightened public. In fact, the findings were held in confidence until they had been carefully reviewed by dozens of competent specialists and even confirmed in other studies.

The public no doubt will be frightened. But in recent years the details of the *known* consequences have repeatedly been underplayed by government representatives and largely ignored by the media and educational authorities. The pervasive feeling among the American public seems to have been that it would never happen or, if it did, it would be terrible, but many would survive and civilization would soon be rebuilt.

The latter myth has now been given the lie, in no uncertain terms. Far worse than merely ruining the economies of the superpowers and their allies—as was the case in Europe and Japan following World War II—nuclear war could render all but uninhabitable the only known habitable planet in the universe. Nothing of value to anyone alive today is likely to survive such a catastrophe—and least of all, the ideologies that supposedly motivated it. The virtues of freedom—or communism—pale when survival is not an available option and there may be no future generations to whom it can be bequeathed.

Advocates of deterrence would have us believe that these findings confirm its value. After all, a nuclear war hasn't happened yet, and the newly perceived consequences only make it that much more unthinkable. Deterrence, therefore, will be more effective than ever.

This view, however, allows for no mistakes, no human or computer error. Yet over the past few years there have been hundreds of computer errors, telling the United States that attack was imminent; no doubt similar errors have been made by less sophisticated Soviet computers. Six months ago human military minds misjudged the intentions of a Korean Airline pilot and killed over 200 civilians—hardly enhancing the credibility of deterrence.

Can the world risk *everything* on the shaky hopes based on deterrence? Even now the Soviets may be moving toward "launch on warning," and tensions between the two superpowers have never been higher. The public—including citizens of every nation on Earth—indeed has reason to be frightened and the right to demand a complete change in policy. ☐

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MEMORANDUM
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ECONOMIC VIABILITY AFTER THERMONUCLEAR WAR: THE LIMITS OF FEASIBLE PRODUCTION

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UNITED STATES AIR FORCE PROJECT RAND

The RAND Corporation
SANTA MONICA · CALIFORNIA

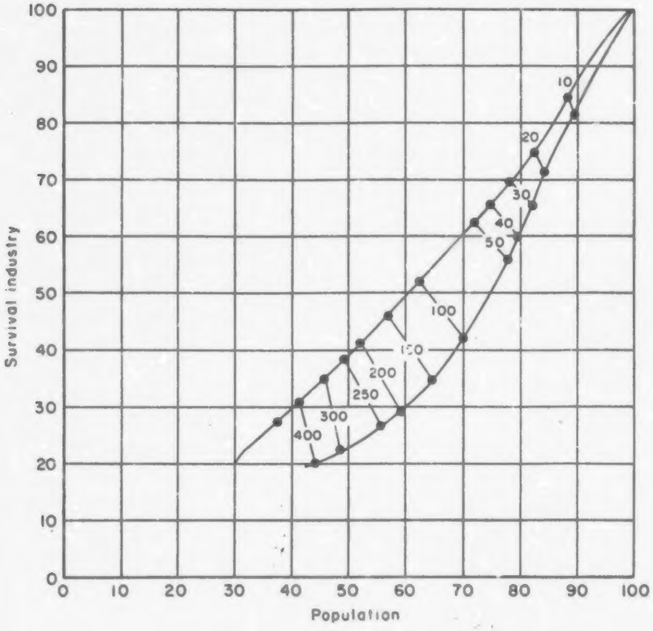

Fig. 4 — Survival curves for attacks on population and on survival industry
(per cent surviving)

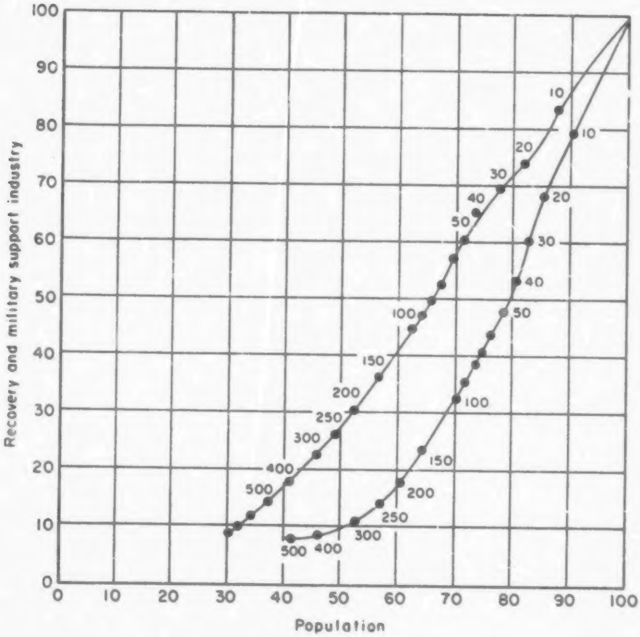

Fig. 5 — Survival curves for attacks on population and on recovery and military-support industry (per cent surviving)

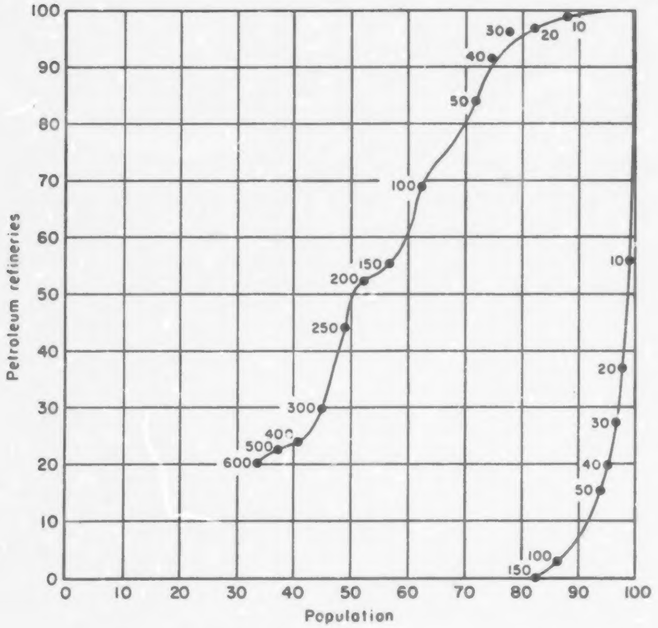

Fig. 6 — Survival curves for attacks on population and on petroleum refineries

(per cent surviving)

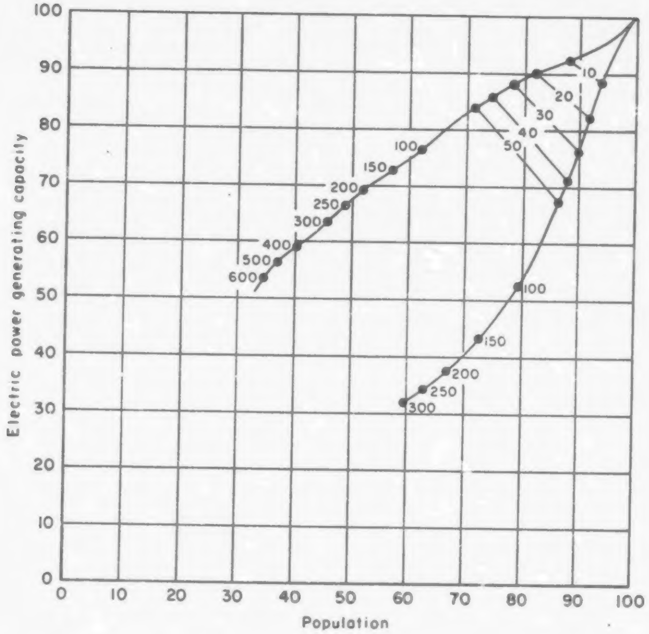

Fig. 7 — Survival curves for attacks on population and on electric power generating capacity
(per cent surviving)

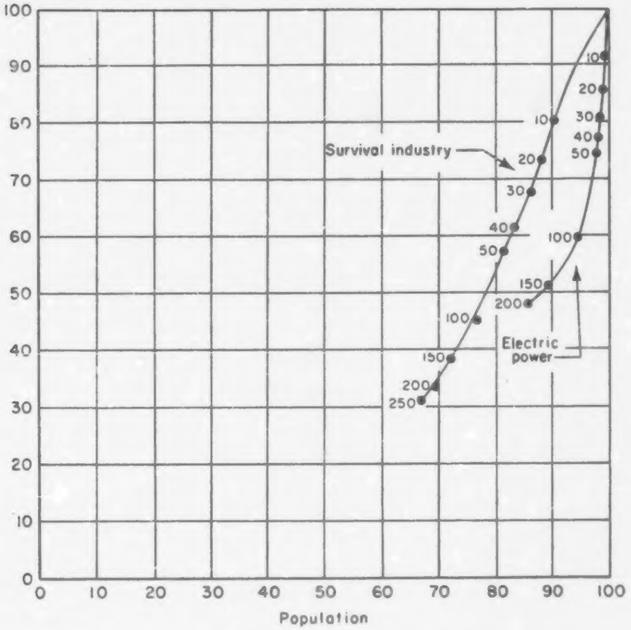

Fig. 8 — Survival curves for population avoidance attacks on survival industry and on electric power generating capacity (per cent surviving)

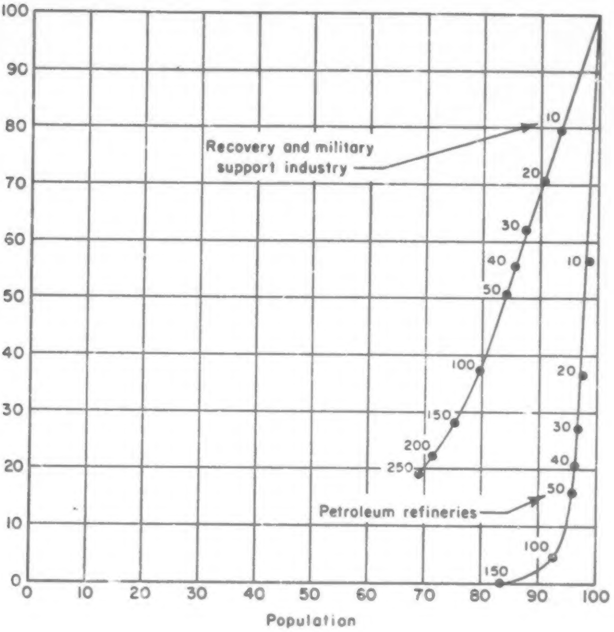

Fig. 9 — Survival curves for population avoidance attacks on recovery and on military support industry and on petroleum refineries (per cent surviving)

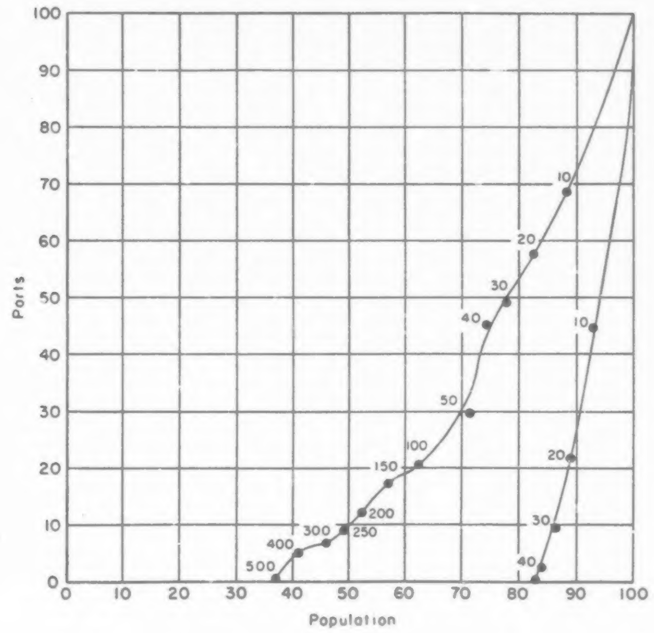

Fig. 10 — Survival curves for attacks on population and on port capacity
(per cent surviving)

CONCLUSIONS

The preceding pages provide no more than a sketch of the many factors that must be taken into account in attempting to delimit the range of postattack situations under which the achievement of economic viability would be technologically feasible. However, a general remark that the problem is complicated and deserves further study is hardly a satisfactory conclusion to an inquiry the basic premise of which is that a quantitative assessment of the probable economic consequences of a thermonuclear war is an essential part of the process of formulating sound national security policy. Although the facts set forth above and the more detailed information that is available do not yield a definitive answer to the questions addressed, they certainly impose some limits on the answers that could plausibly be given. Therefore, I will set forth some informed speculations on these questions, but the reader is warned against taking these quantitative statements too literally.[1]

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[1] The quantitative statements made are based on the survival curves given at the beginning of this section, on the estimates of deaths and casualties presented by N. A. Hanunian and by H. Everett and G. E. Pugh, on miscellaneous sources, and on a good deal of judgment.

It is hardly possible even to describe the full range of conceivable postattack situations, let alone to express a judgment about each of them. The situations examined are those consistent with the following general assumptions: (1) The United States does not suffer a decisive defeat in the war, that is, at a minimum it is left free to conduct its domestic affairs as it wishes; (2) Latin America, Australia, and Africa are not significantly damaged in the war and are willing to trade with the United States on terms not spectacularly inferior to prewar world price ratios, but gratuitous assistance to the United States in its reorganization effort is negligible;[1] (3) The fixed requirement is negligible;[2] (4) The level of subsistence consumption in the first two or three years is not much above physiological subsistence; (5) No significant decline in the effectiveness of surviving members of the labor force occurs as a result of radiation explosures less than those that produce symptoms of mild radiation sickness, or as a result of psychological reactions to the war and the postwar situation; (6) Most of the weapons employed against nonmilitary targets have yields well up in the megaton range, so that the number of weapons involved is not more than, say, one-fifth of the total yield in megatons. Finally, it must be emphasized that technological feasibility is being discussed, and not the actual outcome under any given set of measures for dealing with the organizational aspects of the problem.

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[1] "Negligible" means, in this instance, less than $5 billion a year from all sources. Aid of this magnitude might be very important in terms of results, if it served to alleviate critical bottlenecks. However, in such situations the United States could probably manage to find something to export in order to accomplish the same results. Presumably, the United States could not and would not want to rely on any other nation to serve the kind of organizing function that the United States played in Germany after World War II. Canada might be an exception to this, if it happened to come through the war in much better shape than the United States.

[2] National security expenditures (including foreign aid) plus support of nonproductive survivors would not take a larger share of postattack output than national security expenditures currently take of GNP. Other government expenditures should be regarded as consumption or investment for purposes of viability analysis.

Given these general assumptions, the various situations that might arise will be distinguished according to two characteristics: (1) the total weight of attack on the United States; (2) the weight of attack directed against nonmilitary targets.[1]

Total Weight 1000 Megatons or Less, 500 Megatons or Less on Nonmilitary Targets

Under these conditions, I feel that a failure to achieve viability would be very unlikely, regardless of the targeting of the nonmilitary portion of the attack, and regardless of the measures taken to protect the population. At worst, 100 weapons would be directed against nonmilitary targets. Casualties might approach half of the population in the worst case, but could be much smaller if: the population were moderately prepared, less than 500 megatons were directed against nonmilitary targets, and/or most of the weapons were air burst.[2] The surviving population should not have much difficulty in supporting itself. If the nonmilitary part of the attack were directed at population, per capita availability of most economic resources would not be far below prewar levels. Severe bottlenecks might be created in some narrowly defined industrial categories if the attacker attempted this, but the general adequacy of surviving resources, the food stockpile, and the possibility of trade should certainly make it possible to alleviate these bottlenecks in time.

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[1] For the purposes of this discussion, "military targets" means the U.S. strategic retaliatory force, and "nonmilitary targets" means everything else, except that a small number of important strategic retaliatory force targets are located in or near large cities, and attacks on these would count as part of the nonmilitary attack. On this definition, the destruction of physical capital incidental to a pure military attack would be negligible, though population casualties and other effects might be substantial.

[2] "Casualties" and "deaths" are not equivalent terms; the former includes injuries.

For example, an attempt to create a bottleneck in petroleum refining would not come very close to reducing capacity to zero and would leave the rest of the economy in fairly good condition. If the proportion of the country's area covered by all weapons effects (including fallout) is any guide, the changes produced in the natural environment should not be serious.

Total Weight 1000 to 4000 Megatons, 500 Megatons or Less on Nonmilitary Targets

If all or nearly all targets were attacked with air burst weapons, the prospects for viability after attacks in this range would be about as good as in the previous case. The effects on the nation's industrial plant would be essentially the same, and would be unlikely to pose critical problems. For plausible geographical distributions of the attack, a significant fraction of the country's area might be burned over, but the prospects for postattack agricultural production should not be seriously affected in the short run. If the attacker used surface bursts against most targets, the effects of fallout might create serious obstacles to viability. First, an attacker who used 500 megatons against nonmilitary targets and sought to maximize "bonus" damage from a 3500 megaton attack on military targets could kill a large fraction of the population -- 60 per cent or more -- if no fallout shelters were available. Total casualties might approach 80 per cent of the population. Such a low level of population survival would by itself make the achievement of viability very difficult.[1] Second, a substantial intensification of the pest problem in agriculture would be a possible consequence of the ecological imbalances produced by the period of high radiation levels. The economy would be much less capable of dealing with this problem than it was preattack (even if the attacker did not devote special attention to the pesticides industry), unless special preparations were made. No firm prediction about the seriousness of the resulting situation is justified, but the possibility of a major pest problem introduces some uncertainty into the picture.

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[1] Important skill groups in the labor force would be totally wiped out, and the resulting problems at the strictly organizational level would be enormous.

Certain preparations would have to be made in order to give the economy a "medium confidence" capability for viability after the worst of the attacks in this range. First, the population would have to be moderately well protected against fallout -- the equivalent of protection in an ordinary basement, with windows sandbagged, and stocked for a two week stay. This would probably reduce casualties below the 50 per cent level. Second, preparations would have to be made to assure that production of pesticides could quickly surpass preattack levels, and to guarantee a capability for investigating, analyzing, and attacking pest problems as they appeared. Third, preparations would have to be made for quick restoration of the network industries, and the alleviation of specific bottlenecks elsewhere. The cost of preparedness program of this sort might be expected to be in the one to ten billion dollar range.

Total Weight 1000 to 4000 Megatons, 750 to 2000 Megatons on Nonmilitary Targets

It is believed that this is the range where the loss of industrial capacity would create serious to insuperable obstacles to viability, unless extensive preattack preparations were made. Much would depend on whether the attacker did or did not attempt to maximize the economic difficulties created by the nonmilitary portion of the attack; but if not, the change from the preceding case would be that an additional 15 to 20 per cent of the population would be killed, the balance between surviving population and resources would be less favorable, and there would be more industrial categories in which capacity was reduced close to zero. Good to excellent[1] fallout shelter would be required to keep casualties below 60 per cent of the population. The over-all balance between industrial capacity and population would not be at an obviously disastrous level, even if population survival were well above 50 per cent. It might be possible to achieve viability if the effects on the natural environment did not create a highly unstable ecological situation and preparations were made for dealing with these problems, and if the numerous specific bottlenecks could be alleviated. The last might be accomplished through foreign trade, except that it would be difficult to produce anything for export; and, in addition, a very large fraction of the country's port capacity would certainly be destroyed. Success in achieving viability, without the benefit of more extensive preparations than have thus far been considered, seems quite unlikely.

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[1] By "excellent" fallout shelter is meant something of the sort investigated by the U.S. Naval Radiological Defense Laboratory, with a radiation attenuation factor of 100, resistant to 35 psi of blast overpressure, and affording protection against firestorm as well. (See the testimony of W. E. Strope, Civil Defense, 1961, pp. 233-257.)

If the attacker did choose to attempt to maximize economic difficulties, success would be even less probable. How severely the economy could be crippled by an attack of 2000 megatons in at most 400 weapons is not considered in detail. However, it seems probable that such an attack could destroy 100 per cent of the port capacity and petroleum refineries, incidentally destroying perhaps 40 to 50 per cent of other industrial capacity in general, with some weapons left over. Those additional weapons might well reduce survival in additional industrial categories to close to zero. For the attack pattern that would produce these results, about two-thirds of the population might survive, if excellent fallout shelter were available. Although the food stockpile would last for two or three years, it seems very doubtful that this period would suffice for piecing together the economy after such an attack.

The over-all balance between resources and population would not be critical, and therefore the preparations required to make viability possible after attacks in this range (in addition to those already mentioned) would involve a relatively selective program of stockpiling, construction of underground factories, and so on, in order to forestall the appearance of certain bottlenecks, plus more elaborate preparations to restore transportation, communications, and other services not readily stockpiled or moved underground, plus general preparations to facilitate the repair or partial salvaging of damaged capacity. It is probable that an adequate program of this sort might cost in the low tens of billions of dollars. Of course, if effects on the natural environment turned out to have particularly serious consequences, viability might be unattainable in spite of this degree of preparation.

Total Weight Over 6000 Megatons, 2000 Megatons or Less on Nonmilitary Targets

This case differs from the preceding in that it is no longer necessary to appeal to the possibility of unstable behavior of the ecological system in order to conclude that over most of the area of the country, major uncertainties exist about the prospects for postattack agriculture. The results would, of course, depend quite heavily on the attack pattern.[1] But a fairly even distribution of a 5000 megaton attack over the nation might well result in the burning of 20 to 40 per cent of the nation's area and (if most weapons were surface burst) in levels of radiation lethal to unprotected mammals and birds over 50 to 80 per cent of the nation's area. Unless and until a convincing case can be made that feasible preparations would make these problems manageable, the resulting uncertainties about the prospects for postattack agriculture are a major qualification to any calculation of the potential benefits from economic preparations more extensive than those discussed above. Perhaps an economy could be constructed that would be viable as a heavy importer of foodstuffs and exporter of manufactures. If this is a realistic possibility,[2] the program of preparations that would make it feasible would be markedly different from that based on the assumption that the United States would feed itself, and would probably cost a good deal more.

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[1] In particular, a pure military attack in which all weapons were air burst and several weapons were assigned, on the average, to each target would be very unlikely to make viability impossible. The relevance of the several weapons per target condition is that the areas burned over would be much smaller.

[2] It is doubtful; but it might be possible if the effects on the natural environment did not extend to Canada.

Total Weight Over 6000 Megatons, or 3000 Megatons or More on Nonmilitary Targets

A discussion of still more catastrophic situations is of interest only because further study might lead to a substantial reduction in the uncertainties relative to postattack agriculture, or to the discovery of high confidence ways of meeting the problems. After an attack of 3000 or more megatons (up to 600 weapons) on economic targets, economic viability could be achieved only with the help of preattack preparations that would essentially amount to creating an underground economy sufficiently large and well stocked to be able to meet the subsistence needs of the population after the attack, with little assistance from surviving resources above ground. The construction of such an underground economy would, of course, be a much smaller job than "moving the entire economy underground." In fact, judging by the past accomplishments of the American economy, it is almost certainly a feasible job if carried out over a period of three years or more. My guess would be that $600 billion *substantially overstates* the cost of the "sub-economy"[1] plus excellent shelters (with a good deal of blast protection) for the population.[2]

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[1] This is O. Morgenstern's term. See his proposal for such an economy in *The Question of National Defense*, Vintage Books, New York, 1961.

[2] The reasoning underlying this estimate (such as it is) is as follows: An excellent system of fallout shelters should not cost more than $50 billion at the outside; this sum, in fact should buy systems sufficiently "luxurious" to be habitable for a long period of time after the attack. (See the testimony of W. E. Strope, Civil *Defense, 1961*, pp. 240-245, for discussion of the costs of less "luxurious" shelters.) The stock of privately owned plant and equipment was worth something under $800 billion in 1960 (in 1960 dollars). Considering the low share that subsistence consumption would take of 1960 GNP, the fact that some surviving resources above ground could be counted on, and the fact that the composition of the stock of plant and equipment placed underground could be chosen with postattack needs in mind, it should certainly be possible to get along on one-fourth of

This is $200 billion a year for three years. Suppose (to be realistic about the environment in which such a program might be adopted) that other defense expenditures are running at the rate of $100 billion a year, so that total defense expenditures would be $300 billion a year for the three years. In 1964, operating full blast (World War II conditions), the economy will probably be capable of a GNP of $725 billion or so (1960 dollars).[1] This means defense expenditures equal to about 41 per cent of GNP, just about the same as in 1943 and 1944. Perhaps another year should be allowed for the buildup to this level of expenditure to occur. On the other hand, a large fraction of the expenditure would create capacity that could be put to use before the total program could be completed; that is, the economy would be capable in the later years of a GNP considerably in excess of $725 billion. Thus, subject to the very important qualification that the problems created for agriculture by the changed natural environment must be shown to be manageable, and that three or more years are available

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the 1960 total or about $200 billion worth of plant and equipment (in roughly equal proportions) if the capacity were created above ground. In many manufacturing industries, it appears that underground plants might well be cheaper than plants of equal capacity on the surface, and in only a few industries would costs of subsurface construction be more than twice the costs of ordinary construction. But in some manufacturing industries, and certainly in the case of transportation, major technological advances would be necessary to make underground operation feasible. In these cases, the best solution might well be to stockpile materials, equipment, and components for creating the required facilities on the surface, and to provide the remainder of the underground economy with inventories large enough to support operations until construction could be completed. A factor of three increase over normal plant costs, or a factor of two in plant and equipment combined, should be an adequate allowance for the costs of going underground. This accounts for $400 billion of our estimate. Another $50 billion may be allowed for underground government facilities, water decontamination facilities, hospitals, libraries (especially of technological information), and so forth. This leaves $100 billion for stocks of basic and semifinished materials, including augmentation of the food inventory, and miscellaneous needs.

[1] This assumes that full employment GNP will grow at an annual rate of about 3.5 per cent, starting from 1960, and that "full blast" GNP exceeds full employment (4 per cent unemployment) GNP by about 20 per cent.

for the task, and subject to the six assumptions made above, it may be concluded that it would be economically feasible to make preparations to assure at least the technological possibility of achieving viability after very large nuclear attacks. Although it is not within the scope of this study to discuss the desirability of undertaking such a program, it should be noted that a decision to embark on such a program might provoke a decision on the part of the Soviet Union to develop the means to negate it.

Senator **Proxmire**. Gentlemen, I want to thank you very, very much. You've been most helpful.

Mr. Winter, we are delighted to have you and you certainly were very helpful to us.

Mr. McLoughlin, you came on short notice and, while we have many criticisms of your agency, I think you were extraordinarily responsive and knowledgeable and very impressive.

Thank you. The subcommittee will stand adjourned. .

[Whereupon, at 4:46 p.m., the subcommittee adjourned, subject to the call of the Chair.]

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